# Design of Welded Joints

ME 310: Mechanical Design

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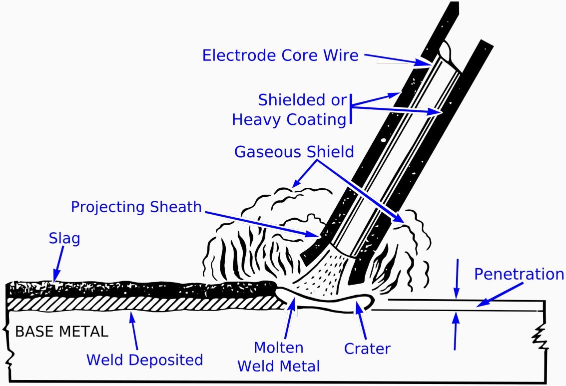
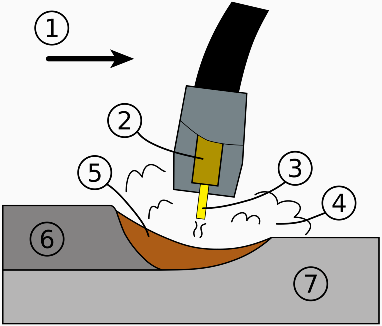
# Outline

# Shielded Metal Arc Welding



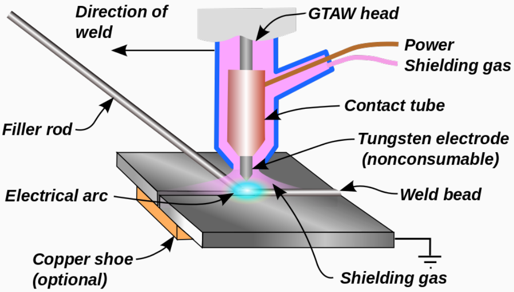

Electric arc to produce heat

# MIG Welding



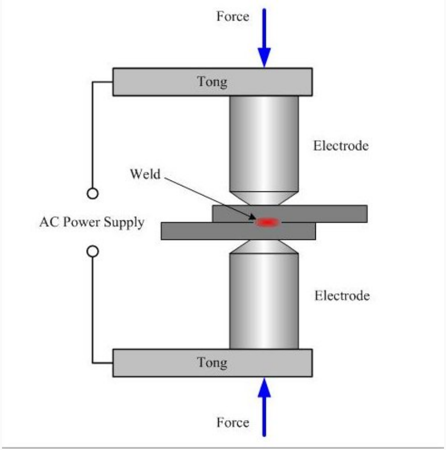

- uses consumable electrode
- simple to learn
- welds aluminum, nonferrous, and stainless steel
- expensive
- neat but difficult to troubleshoot

# TIG welding




- nonconsumable electrode
- difficult to learn and troubleshoot
- welds almost all materials
- preferred welding in precision and fabrication industry

# Resistance Welding



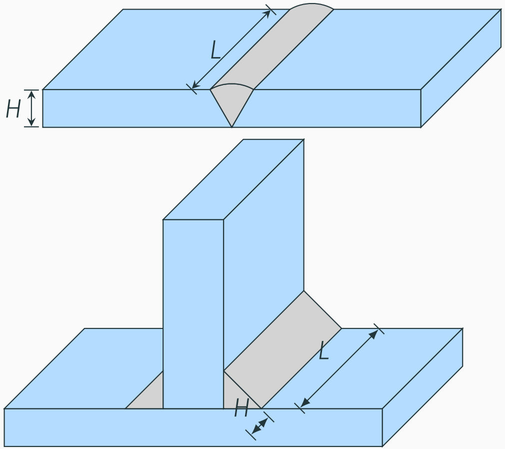

- uses Joules heating ($i^2R$) to generate heat
- often require large current (1000 - 100000 A)
- widespread use in automotive industry

# Gas Welding


- uses combustion (Acetylene + $O_2$) to generate heat
- slow but cheap
- mainly for maintenance purposes.

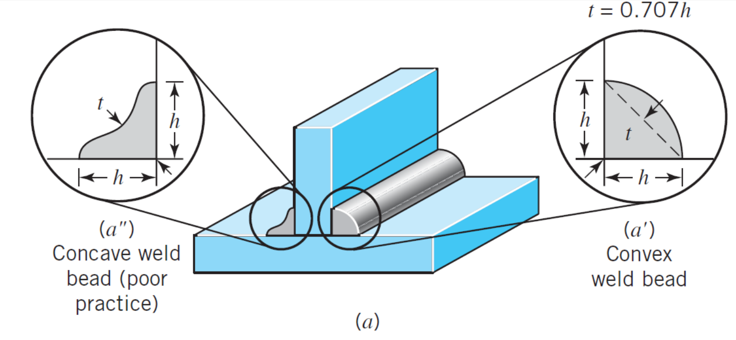
# Outline

# Weld type




- butt welds
- fillet welds

# Good Welds vs Bad Welds

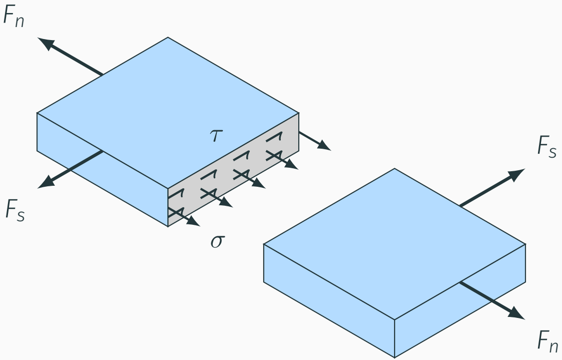


# Outline

# Welding Electrodes

| AWS Number | Electrode | Tensile Strength (MPa) | Yield Strength (MPa) | Percent Elongation |
|---|---|---|---|---|
| E60XX | | 427 | 345 | 17-25 |
| E70XX | | 482 | 393 | 22 |
| E80XX | | 551 | 426 | 19 |
| E90XX | | 620 | 531 | 14-17 |
| E100XX | | 689 | 600 | 13-16 |
| E120XX | | 827 | 737 | 14 |

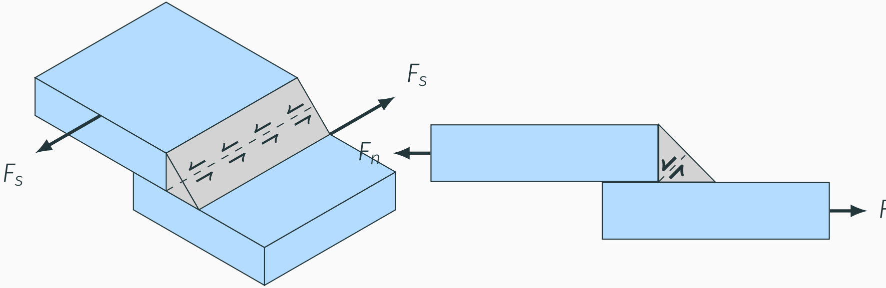
# Stress in Butt Welds




$$\sigma = \frac{F_n}{A_w} = \frac{F_n}{HL}$$

$$\tau = \frac{F_s}{A_w} = \frac{F_s}{HL}$$

# Stress in Fillet Welds




$$\tau = \frac{F_s}{HL}$$

$$\tau = \frac{F_n}{HL}$$

# Stress in weld groups

Assumptions

- parts being joined are rigid
- torsional and bending stresses can be found by

$$\tau = \frac{Tr}{J}$$
$$\sigma = \frac{My}{I}$$

- must determine $I$ and $J$ of welds

# Finding $I$ and $J$ of welds

- Need to find center of rotation / neutral axis $\rightarrow$ weld center
- Single weld – centroid of weld cross-section
- Multiple weld – centroid of weld group

$$x_c = \frac{\int_A x dA}{A} = \frac{\sum x_{ci} A_i}{\sum A_i}$$
$$y_c = \frac{\int_A y dA}{A} = \frac{\sum y_{ci} A_i}{\sum A_i}$$

# Evaluating $I$ and $J$ for Individual Weld

- for weld whose neutral axis passes through centroid / center of rotation coincides with centroid

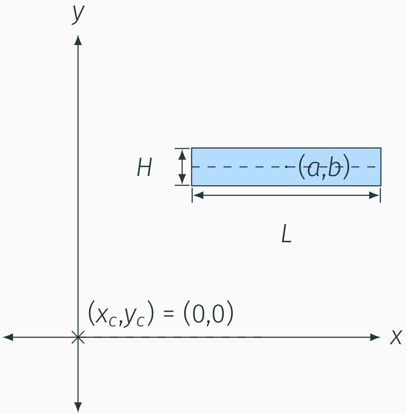
$$I_c = \frac{LH^3}{12}$$

$$J_c = \frac{LH^3}{12} + \frac{HL^3}{12}$$

- with multiple welds, neutral axis and/or center of rotation rarely coincides with individual centroids.

# Finding $I$ and $J$ for multiple welds

- Once weld center is found, find $I$ and $J$ according to the center



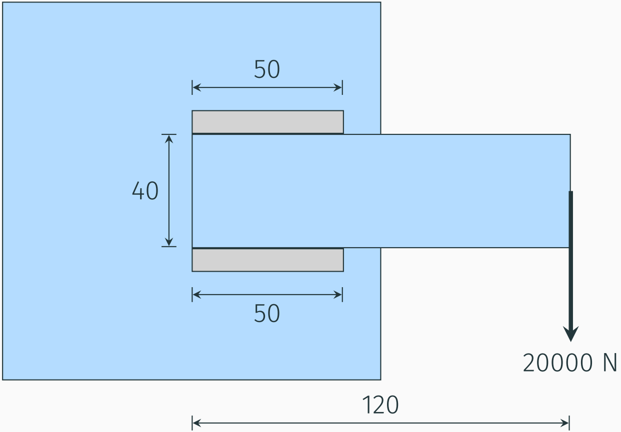

$$I_{group} = I_c + Ad^2 = I_c + Ab^2$$

$$J_{group} = J_c + Ar^2 = J_c + A(a^2 + b^2)$$

- Need to apply parallel axis theorem (if applicable)

# Weld Joints under Torsion Example

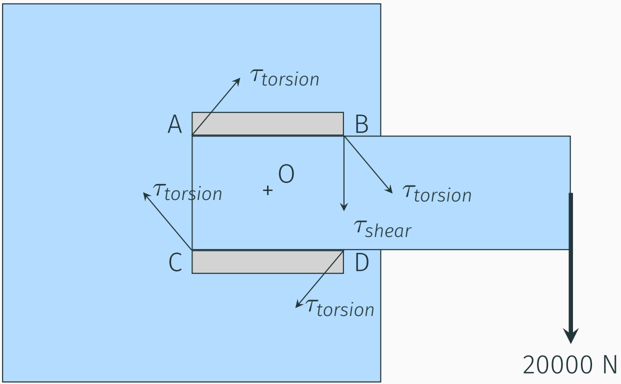
Determine the critical point in the welds and its state of stress. The weld throat thickness is 8 mm.



## Break It Down

- Problem of shear loading + torsion
- Splitting the resultant stresses to analyze critical point

# Combination of Stresses

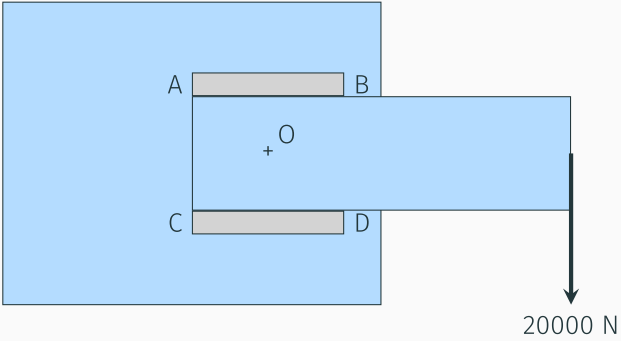


# Shear Force

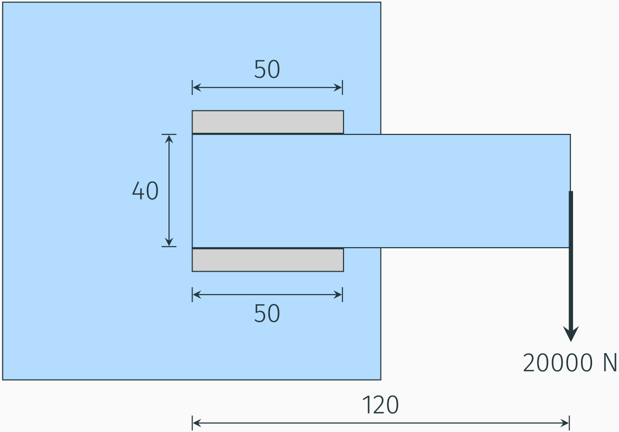
$$\tau_{shear} = \frac{P}{2HL} = \frac{20000}{2(0.008)(0.05)}$$
$$= 25 \text{ MPa}$$

# Torsion

- Symmetric welds $\rightarrow$ center of weld is at O




$$\tau_{torsion} = \frac{Tr}{J_{group}} = \frac{PL_o r_o}{J_{group}}$$
$$= \frac{20000(0.12 - 0.05/2)r_o}{J_{group}}$$




$$r_o = \sqrt{\left(\frac{L}{2}\right)^2 + d_o^2}$$

$$r_o = \sqrt{\left(\frac{0.05}{2}\right)^2 + 0.02^2}$$

$$= 0.032 \text{ m}$$

# $J_c$ of Welds

$$
\begin{aligned}
J_{group} &= J_c + Ad_o^2 \\
&= 2\left[\frac{HL^3}{12} + \frac{LH^3}{12} + LHd_o^2\right] \\
&= 2\left[\frac{(0.008)(0.05)^3}{12} + \frac{(0.05)(0.008)^3}{12} + (0.05)(0.008)(0.02)^2\right] \\
&= 1.70 \times 10^{-5}\ \mathrm{m}^4
\end{aligned}
$$

# Shear Stress from Torsion

Now we have all the parameters we need, so we can substitute them back into the torsional shear stress equation, which gives

$$\begin{aligned}\tau_{torsion} &= \frac{20000(0.12 - 0.05/2)r_o}{J_{group}} \\ &= \frac{20000(0.095)(0.032)}{1.7 \times 10^{-5}} \\ &= 3.58 \text{ MPa}\end{aligned}$$

# Combining the Stress

- Combine using vector addition equation

$$
\begin{aligned}
\left|\vec{\tau}_{torsion} + \vec{\tau}_{shear}\right|^2 &= \left|\vec{\tau}_{torsion}\right|^2 + \left|\vec{\tau}_{shear}\right|^2 + 2\vec{\tau}_{torsion} \cdot \vec{\tau}_{shear} \\
&= \left|\vec{\tau}_{torsion}\right|^2 + \left|\vec{\tau}_{shear}\right|^2 + 2\left|\vec{\tau}_{torsion}\right|\left|\vec{\tau}_{shear}\right| \cos\alpha
\end{aligned}
$$

# Finding $\alpha$

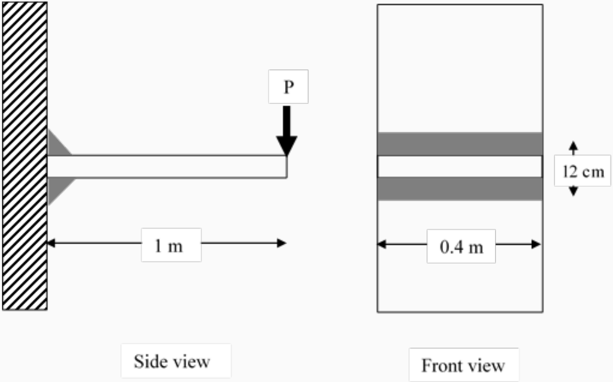
- We don't really need $\alpha$, just $\cos\alpha$

$$\cos\alpha = \frac{L/2}{r_O} = \frac{L}{2r_O}$$
$$= \frac{0.05}{2(0.032)} = 0.78$$

- Substitute $\alpha$ into the vector addition formula to obtain the combined shear stress

$$|\vec{\tau}_{torsion} + \vec{\tau}_{shear}|^2 = 25^2 + 3.58^2 + 2(25)(3.58)(0.78)$$
$$= 778$$
$$|\vec{\tau}_{torsion} + \vec{\tau}_{shear}| = |\vec{\tau}_{total}| = 27.9 \text{ MPa}$$

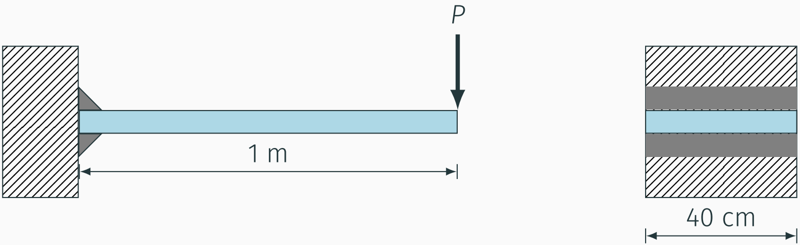
# Stress in Weld joints under Bending




$$\sigma = \frac{My}{I_{group}}$$

# Weld under Bending Example

Determine the maximum load $P$ that can be applied to the structure as shown below, given that the safety factor of the weld is 3. The weld has the effective throat thickness of 3 mm, and is made with E70XX series electrode.



# Break It Down

- Shear force + bending
- Same stresses throughout
- From shear force

$$\tau = \frac{P}{2HL} = \frac{P}{2(0.003)(0.4)} = 417P$$

# Finding Bending Stress

$$\sigma = \frac{My}{I} = \frac{P(1)(0.06)}{I} = 0.06\frac{P}{I}$$

$$\begin{aligned}
I_y &= 2\left(\frac{LH^3}{12} + LHa^2\right) \\
&= 2\left(\frac{(0.4)(0.003)^3}{12} + (0.4)(0.003)(0.06)^2\right) \\
&= 8.64 \times 10^{-6}\ \mathrm{m}^4
\end{aligned}$$

$$\sigma = 0.06\frac{P}{8.64 \times 10^{-6}} = 6944P$$

# Evaluating Weld Strength

- Welds are considered brittle $\rightarrow$ MNST

$$\sigma_1 = \frac{6944P}{2} + \sqrt{\left(\frac{6944P}{2}\right)^2 + (417P)^2}$$
$$= 6969P$$
$$N_s = \frac{\text{strength}}{\text{stress}}$$
$$3 = \frac{482 \times 10^6}{6969P}$$
$$P = 23000 \text{ N}$$

- Weld strength only
- Actual allowable force may be less, depending on the strength of the beam itself.

# Outline

# Weld geometry and Fatigue

Reinforcement under static loading is not a problem

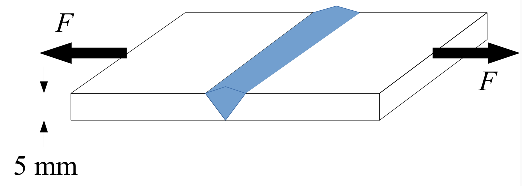
- under fatigue it *is*

# Fatigue stress concentration factor, $K_f$

| Type of Weld | $K_f$ |
|---|---|
| Reinforced butt weld | 1.2 |
| Toe of transverse fillet weld | 1.5 |
| End of parallel fillet weld | 2.7 |
| T-butt joint with sharp corners | 2.0 |

# Fatigue in Welded Joint Example

A butt weld is subjected to a repeated axial load *F* ranging from 50000 to 100000 N as shown. The thickness of the material is 0.5 cm. The joint is welded with E60 series electrode. Determine the proper weld length if the required safety factor is 3.



# Faigue in Welded Joint Solution

Based on Soderberg relation, we have that

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_y} = \frac{1}{N_s}$$

We can simply calculate the amplitude and average stresses.

$$\sigma_m = \frac{100000 + 50000}{2HL} = \frac{75000}{0.5 \times 10^{-2} L} = \frac{1.5 \times 10^7}{L}$$

$$\sigma_a = \frac{100000 - 50000}{2HL} = \frac{25000}{0.5 \times 10^{-2} L} = \frac{5 \times 10^6}{L}$$

However, due to stress concentration from reinforced butt weld, the actual average stress and stress amplitudes are

$$\sigma_m = 1.2\left(\frac{1.5 \times 10^7}{L}\right) = \frac{1.8 \times 10^7}{L}$$

$$\sigma_a = 1.2\left(\frac{5 \times 10^6}{L}\right) = \frac{6 \times 10^6}{L}$$

The yield strength and endurance limit for E60 series are 345 MPa and $0.45 \times 427 = 192$ MPa, respectively. Substituting the values into Soderberg relation, we have

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_y} = \frac{1}{N_s}$$

$$\frac{1}{L}\left(\frac{6 \times 10^6}{192 \times 10^6} + \frac{1.8 \times 10^7}{345 \times 10^6}\right) = \frac{1}{3}$$

$$L = 2.5 \times 10^{-1} = 25 \text{ cm}$$