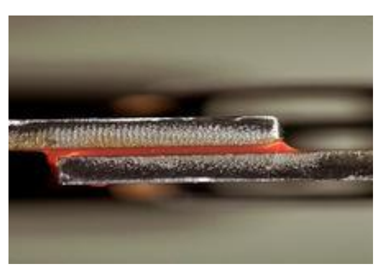
Joint Design

ME 313: Mechanical Design
Week 7

Joints

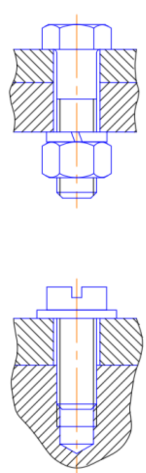
- Use to join two or more components together
- Transfer force/displacement between components



Types of Joints

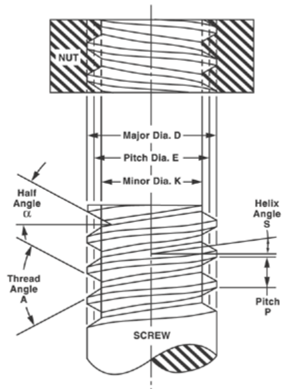
- Nonpermanent joints
  - Bolted joints
- Permanent Joints
  - Welded joints
  - Adhesive joints

Bolted Joints



- Use tension in screws to hold components together
- Usually made up of
  - Screw (or bolt)
  - Nut
  - Two or more workpieces

Screw Thread Geometry



- Major diameter (D)
  - Largest diameter
- Minor diameter (d)
  - Smallest diameter
- Pitch diameter
  - Diameter where width of thread and of space are equal
- Pitch
  - Distance between two adjacent threads

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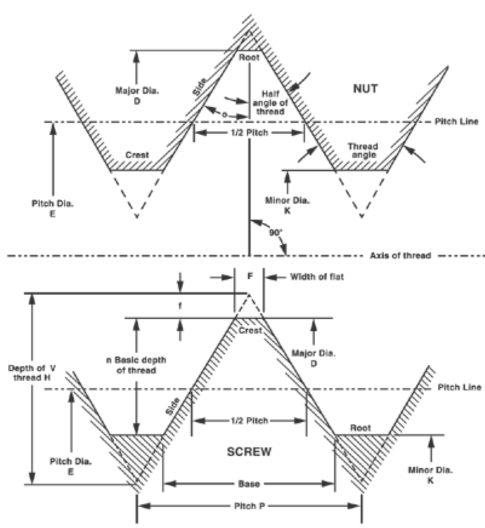
Pitch Diameter Illustration



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Screw Thread System

- Unified Screw Threads Series
  - UNC – coarse threads
  - UNF – fine threads
- Constant Pitch Series
- Metric Screw Threads Series

Unified Threads Series

- Coarse threads
  - For fast assembly and disassembly
  - For low strength materials: mild steel, copper, aluminum
- Fine threads
  - For short thread engagement (thin component)
  - For high strength materials

UNC-UNF Screw Geometries

UNC Size	Major Dia	Threads Per Inch
#	inch	tpi
#1	0.073	64
#2	0.086	56
#3	0.099	48
#4	0.112	40
#5	0.125	40
#6	0.138	32
#8	0.164	32
#10	0.19	24
#12	0.216	24
¼	0.25	20
5/16	0.3125	18
3/8	0.375	16
7/16	0.4375	14
½	0.5	13
9/16	0.5625	12
5/8	0.625	11
¾	0.75	10
7/8	0.875	9
1	1	8

UNF Size	Major Dia	Threads Per Inch
#	inch	tpi
#0	0.06	80
#1	0.073	72
#2	0.086	64
#3	0.099	56
#4	0.112	48
#5	0.125	44
#6	0.138	40
#8	0.164	36
#10	0.19	32
#12	0.216	28
1/4	0.25	28
5/16	0.3125	24
3/8	0.375	24
7/16	0.4375	20
1/2	0.5	20
9/16	0.5625	18
5/8	0.625	18
3/4	0.75	16
7/8	0.875	14
1	1	12

Constant Pitch and Metric Series

- Constant Pitch Series
  - Fixed number of threads per inch
  - Have 4, 6, 8, 12, 16, 20, 28, 32 threads per inch
- Metric Series
  - Major diameters in metric unit

Pairing with Screws

- Screws are paired with nuts or threaded components of the same diameter and thread count
- Thread components are made by first drill a hole and use a thread maker to cut threads

Bolted Joint Stiffness

- Twisting the screw stretches it, producing a clamping force—*bolt preload*
- Stiffness composed of two part
  - Unthreaded portion
  - Threaded portion
- Total stiffness is the spring connected in series

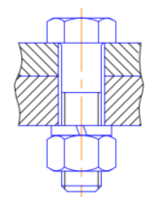
$$\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2} \quad \text{or} \quad k = \frac{k_1 k_2}{k_1 + k_2}$$

Fastener Stiffness (cont)

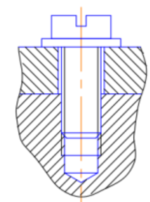
- Stiffness of bolt in clamped area is

$$k_T = \frac{A_t E}{l_t} \qquad k_d = \frac{A_d E}{l_d}$$

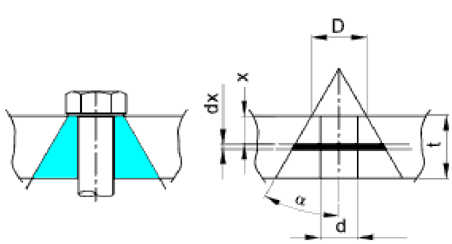
$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d}$$



- A_t = minor-diameter area of bolt
- L_t = length of threaded portion of the grip
- A_d = major-diameter area of bolt
- L_d = length of unthreaded portion in grip



Member Stiffness



- D is diameter of washer
- d is the minor diameter
- t is the grip length (thickness)
- α is the pressure cone angle

$$k_m = \frac{\pi E d \tan\alpha}{2\ln\dfrac{(l\tan\alpha + D - d)(D + d)}{(l\tan\alpha + D + d)(D - d)}}$$

External Tensile Load on Bolted Joints

- If the bolt has been preloaded to F_i and there is external load P
  - The load will cause the joint to stretch

$$P_b = \frac{k_b P}{k_b + k_m}$$

$$F_b = P_b + F_i = \frac{k_b P}{k_b + k_m} + F_i$$

$$F_m = P_m - F_i = \frac{k_m P}{k_b + k_m} - F_i = (1 - C)P - F_i$$

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Relating Bolt Torque to Bolt Tension

$$T = KF_i d$$

- K is called a torque coefficient
- F_i is the tension in the bolt
- d is the minor diameter

Bolt Condition	*K*
Nonplated, black finish	0.30
Zinc-plated	0.20
Lubricated	0.18
Cadmium-plated	0.16

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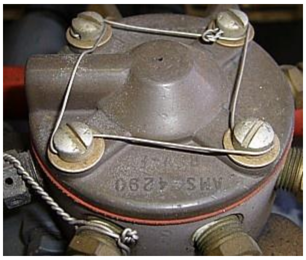
Gasketed Joint



- Use to keep pressure/fluid inside

$$p = \frac{-F_m}{A_g / N}$$

$$F_m = -F_i = -\frac{pA_g}{N} = -\sigma A_t$$

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Examples

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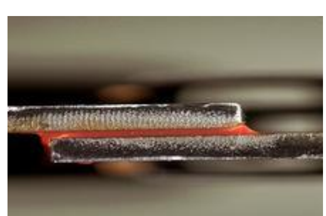
Questions

Permanent Joints

- Welded joints

- Adhesive joints



Welding

- Joining workpieces by partial melting, adding filler, and letting the joints cool

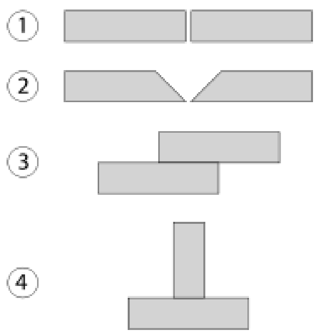
Types of Welding Processes

- Arc Welding
  - heat from electrical arc

- Gas Welding
  - Heat from gas combustion

- Resistance Welding
  - Heat from component resistance

Geometry of Welded Joints



1. Square butt joint
2. V-butt joint
3. Lap joint
4. T-joint

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Weld Electrode Properties

Table 10-24. Typical Analysis and Mechanical Properties of Submerged Arc Flux-Wire Combinations

Wire/Flux Classification	Typical Deposit Chemistry C	Mn	Si	P	S	Typical Mechanical Properties: Tensile Strength psi	Yield Strength psi	Elong. % in. 2"	Reduction of area %	Charpy V-Notch Impact Value Ft-lb	°F
EL12	0.09	0.50	0.01	0.020	0.025						
F60-EL12	0.06	0.70	0.75	0.025	0.020	70,300	60,100	27.0	48.0	--	
F63-EL12	0.04	1.18	0.48	0.036	0.011	72,000	56,000	35.0	67.0	30	-40
EH14	0.14	1.85	0.04	0.010	0.018						
F62-EH14	0.08	1.05	0.55	0.020	0.016	72,000	58,000	29.0	58.0	30	-20
F72-EH14	0.08	1.80	0.65	0.016	0.018	88,000	73,000	28.0	56.0	24	-20
F64-EH14	0.12	1.17	0.24	0.022	0.021	71,000	57,000	31.0	59.1	24	-60
EM15K	0.15	1.10	0.25	0.022	0.025						
F70-EM15K	0.09	0.93	0.94	0.027	0.022	81,700	67,000	30.0	61.0	--	
F72-EM15K	0.08	1.54	0.79	0.025	0.021	82,000	58,500	30.0	59.0	26	-20
F64-EM15K	0.11	0.78	0.30	0.022	0.025	70,000	55,000	29.5	56.5	21	-60
(same as above)	0.13	1.95	0.04	0.010	Mo.53						
Weld stress	0.07	1.95	0.70	0.020	Mo.35	99,250	84,000	25.0	57.0	23	-20
relieved	0.08	1.17	0.23	0.017	Mo.38	80,000	65,500	27.0	66.2	22	-60
EM13K	0.11	1.20	0.50	0.020	0.019						
F70-EM13K	0.09	1.74	1.17	0.017	0.026	86,000	66,500	26.0	53.2	--	
F64-EM13K	0.10	0.90	0.54	0.016	0.020	70,500	54,000	31.0	62.8	29	-60

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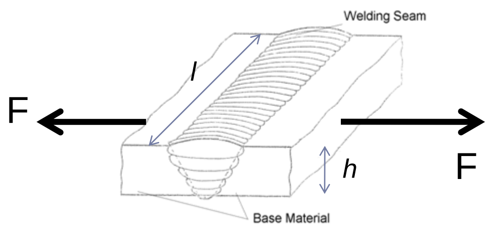
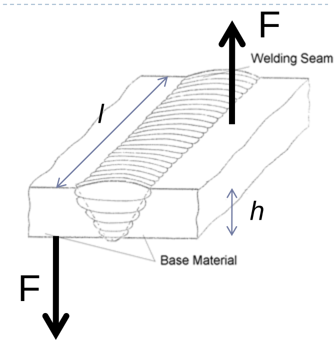
Weld Stress Analysis

- For butt welds

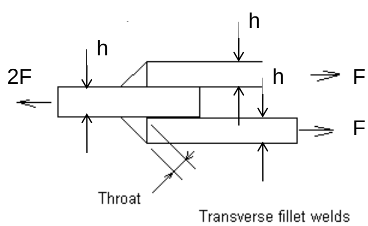




$$\sigma = \frac{F}{hl}$$

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

Fillet Welds Under Axial Loads



$$\sigma = \frac{F\cos\theta(\cos\theta + \sin\theta)}{hl}$$

$$\tau = \frac{F\sin\theta(\cos\theta + \sin\theta)}{hl}$$

- Normal and shear stresses depend on orientation of consideration
  - Stresses listed not considering stress concentration

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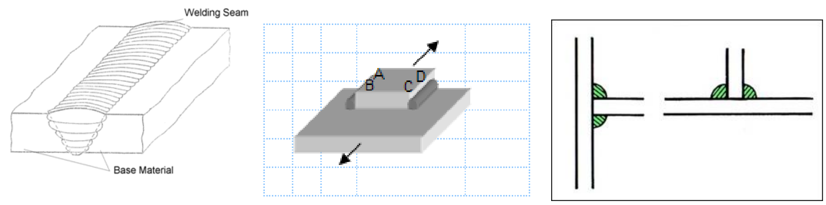
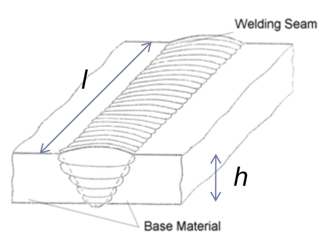
Stress Concentration in Welded Joints



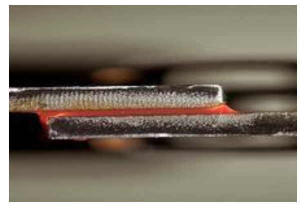
Type of Weld	Stress Concentration Factor
Reinforced butt weld	1.2
Toe of transverse fillet weld	1.5
End of parallel fillet weld	2.7
T-butt joint with sharp corners	2.0

Design Parameters



- Pattern of weld (distribution, *b*, *d*)
- Type of weld (depends on material and thickness)
- Length of weld *l*
- Leg size *h*

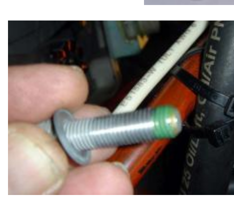
Adhesive Joints



- The use of 'glue' to join parts
- Most effective use is to prevent shearing

Types of Adhesives

- Structural adhesives
  - Can carry significant stresses
    - Epoxies
- Nonstructural adhesives
  - Pressure sensitive
    - Duct tapes, scotch tapes, labels
  - Contact sensitive
    - Rubber cement
  - Anaerobic
    - Thread locking glue

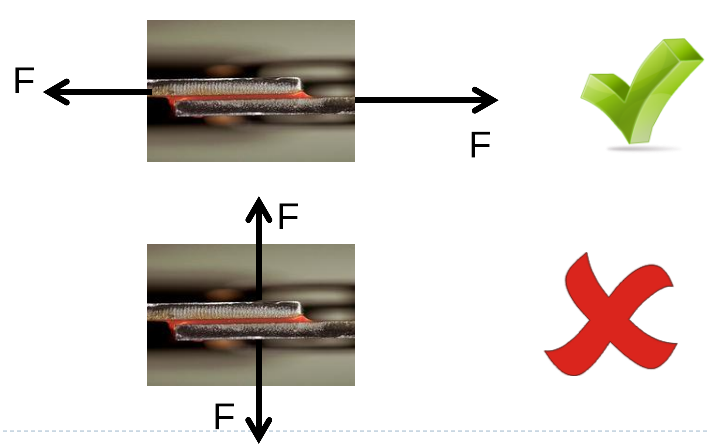


Mechanical Performance of Typical Adhesives

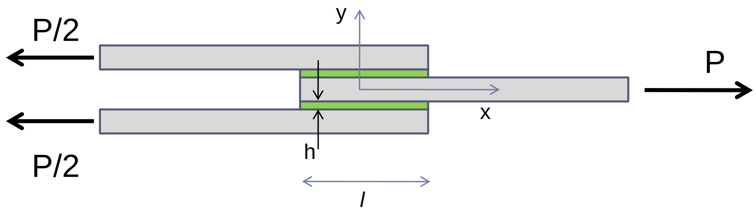
Adhesive Type	Lap-Shear Strength (MPa)	Peel Strength per unit width, kN/m
Pressure sensitive	0.01-0.07	0.18-0.88
Starch-based	0.07-0.7	0.18-0.88
Rubber-based	0.35-3.5	1.8-7
Urethane	6.9-17.2	1.8-8.8
Phenolic	13.8-27.6	3.6-7
Epoxy	10.3-27.6	0.35-1.8
Rubber-modified epoxy	20.7-41.4	4.4-14

Basic Adhesive Joint Design

- Good design allows adhesive to carry load in *__shear, not tension__*



Shear Stress Distribution in Adhesive Lap Joint



$$\tau(x) = \frac{P\omega}{4b\sinh(\omega l/2)}\cosh(\omega x) + \frac{P\omega}{4b\cosh(\omega l/2)}\left(\frac{2E_0t_0 - E_it_i}{2E_0t_0 + E_it_i}\right)\sinh(\omega x) + \frac{(\alpha_i - \alpha_0)\Delta T\omega}{(1/E_0t_0 + 2/E_it_i)\cosh(\omega l/2)}\sinh(\omega x)$$

where

$$\omega = \sqrt{\frac{G}{h}\left(\frac{1}{E_0t_0} + \frac{2}{E_it_i}\right)}$$

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Residual Stresses in Adhesive Joint

- When joint constructing temperature is different from operating temperature
  - Mismatch in coefficient of thermal expansions result in residual stress

$$\sigma_0 = \frac{E_a}{1-\nu_a}(\alpha - \alpha_a)\Delta T$$

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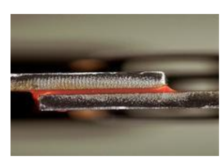
Designing with Adhesive

- Be aware of environmental effect
  - Degradation due to heat, light, or corrosion
- Design for easy inspection
  - Harder to detect degraded bond than missing bolts
- Allow sufficient bond area
  - Debonding should be expected. Allow some debonding before joint breakage
- Creep is an issue
  - Temperature + load + adhesive = creep. Choose the right adhesive for the operating temperature

Comparison between Joint Types





Properties	Bolted Joints	Welded Joints	Adhesive Joints
Weight	High	Small	Small
Joint strength	High	High	Low
Part count	High	Low	Low
Assembly time	Low	High	Low
Labor Skill Required	Low	High	Low
Cost	High	High	Low

Questions?