2.008 Design & Manufacturing II

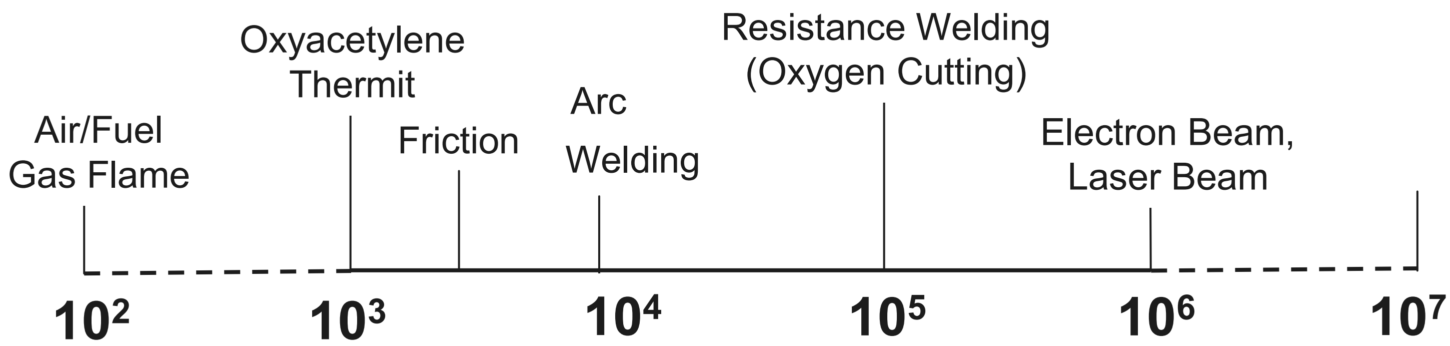
Welding & Joining (rev)

Info

- Quiz 1 on Wednesday, October 26th, 12:30 PM, Room 35-225
  - Closed book (75 minutes), calculator OK
  - Lecture notes up to Welding & Joining, Psets #1 to #5
  - Q&A session (recitation): Oct. 24th, Monday, 7:30PM -9 PM, 35-225
- Plant Tour on Nov. 9th, 10th
- Yo-Yo Design Help
- Welding, Forming today
- 008 Forensics
  - F1, F2 talks
  - D, E next Monday
  - C1, C2 pick topics

Heat Intensity

- A measure of power radiation intensity, W/cm^2



- Higher intensity, higher heat flux, the faster the melting
- Automation needed to prevent overmelting, vaporizing
- For a planar heat source on steel,

  $t_m = (5000/H.I.)^2$

  Oxy: 20-30 sec, E-beam: μ sec

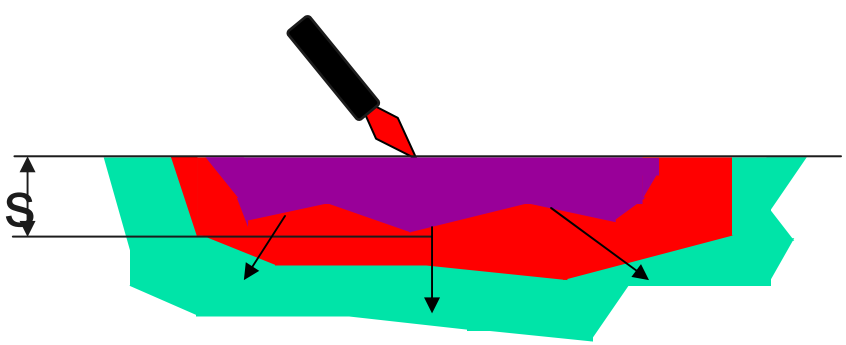
Melting front speed
2D simplification

The Jacob number, $J_a = c_p \frac{(T_{melt} - T_{initial})}{h_{fs}}$.

$h_{fs} = 247$ J/g for steel

The thermal diffusivity is given by $\alpha = \frac{k}{\rho c_p}$.

The melt front moves as : $s = \sqrt{2\alpha J_a t}$



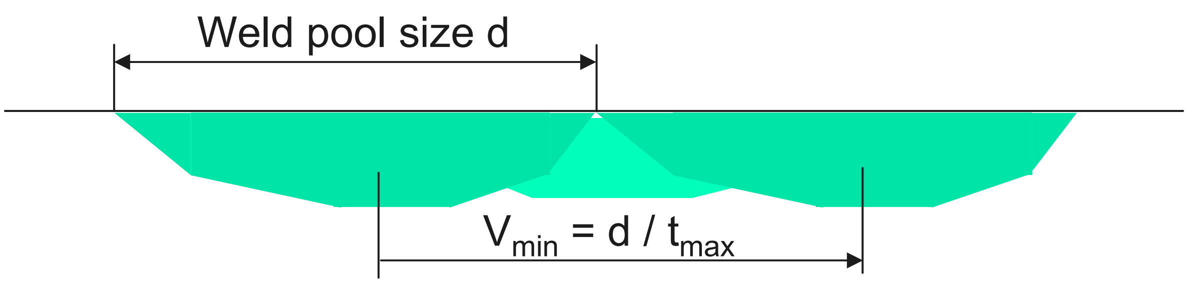
Heat intensity and interaction time

- Heat intensity (in W/cm^2)
  - HI = Power per unit area directed into the welding zone
- Propagation of heat in solids: $s \sim (\alpha \cdot t)^{0.5}$
  - s = distance thermal disturbance travels into thick slab
  - t = elapsed time

	ρ g/cm3	k W/m/K	cp J/g/oC	α cm^2/s	Tmelt oC	oF
Aluminum	2.7	200	0.890	0.832	660	1220
Copper	8.9	400	0.385	1.167	1085	1985
1020 steel	7.9	50	0.448	0.141	1500	2732
Delrin	1.4	0.36	1.464	0.002	175	347

Welding speed

- $t_{max} = (s_m)^2 / (2\ \alpha\ Ja)$,
- Any longer stay than t_{max}, over-melt!



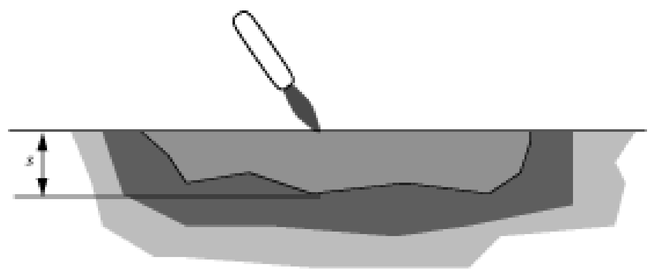
- If the weld pool size is *d* in diameter, then you must feed at a rate that exceeds $v = d/t_{max}$ → welding speed
- HI increases, welding speed must go up
- α Ja increases, interaction time must go up

Melting front and welding velocity

- Definitions of Jacob # and thermal diffusivity:

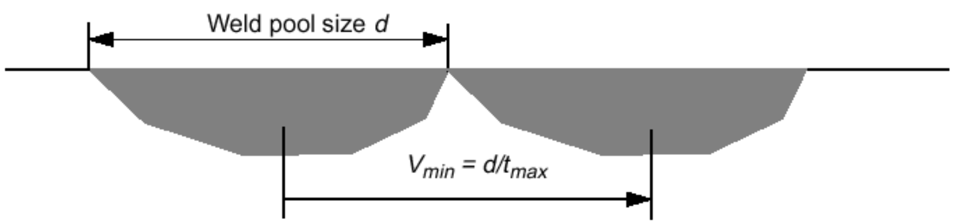
$$J = c_p \cdot \frac{T_{melt} - T_{initial}}{h_{fs}} \qquad \alpha = \frac{k}{\rho \cdot c_p}$$

- Solidification front moves in "s" direction as:



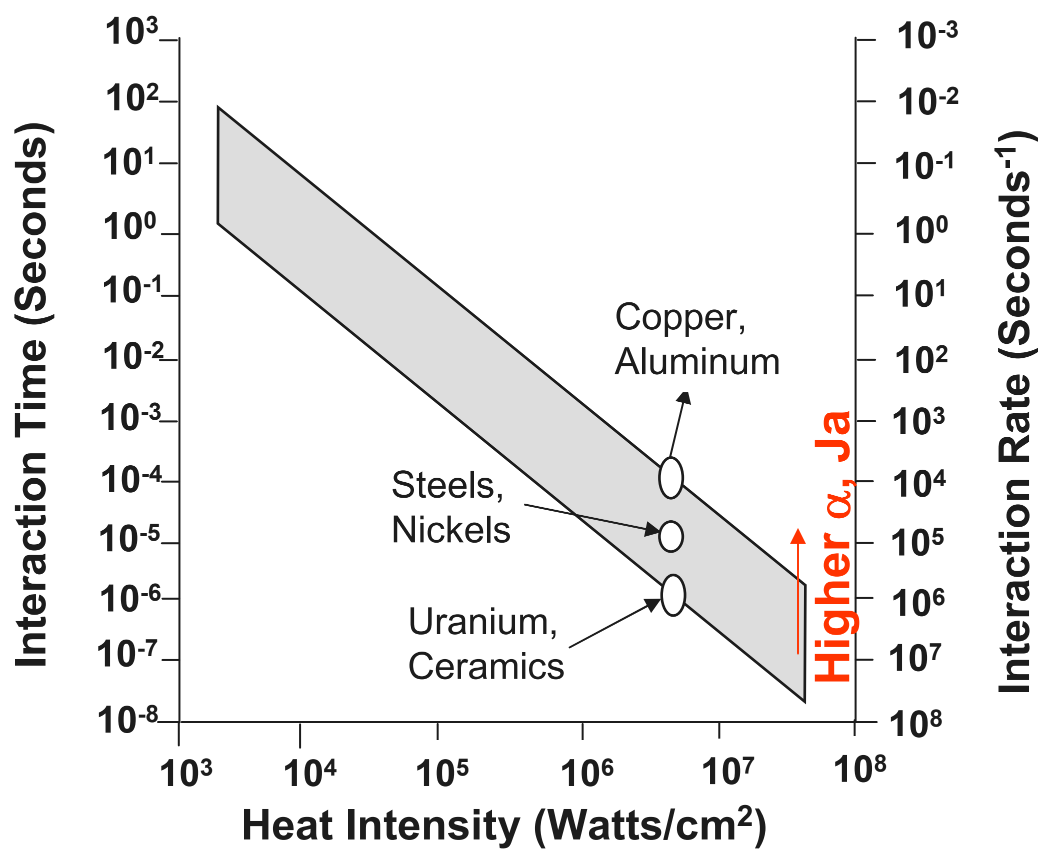
$$s = \sqrt{2 \cdot \alpha \cdot J \cdot t_{\max}}$$

- To maintain constant weld pool depth at s



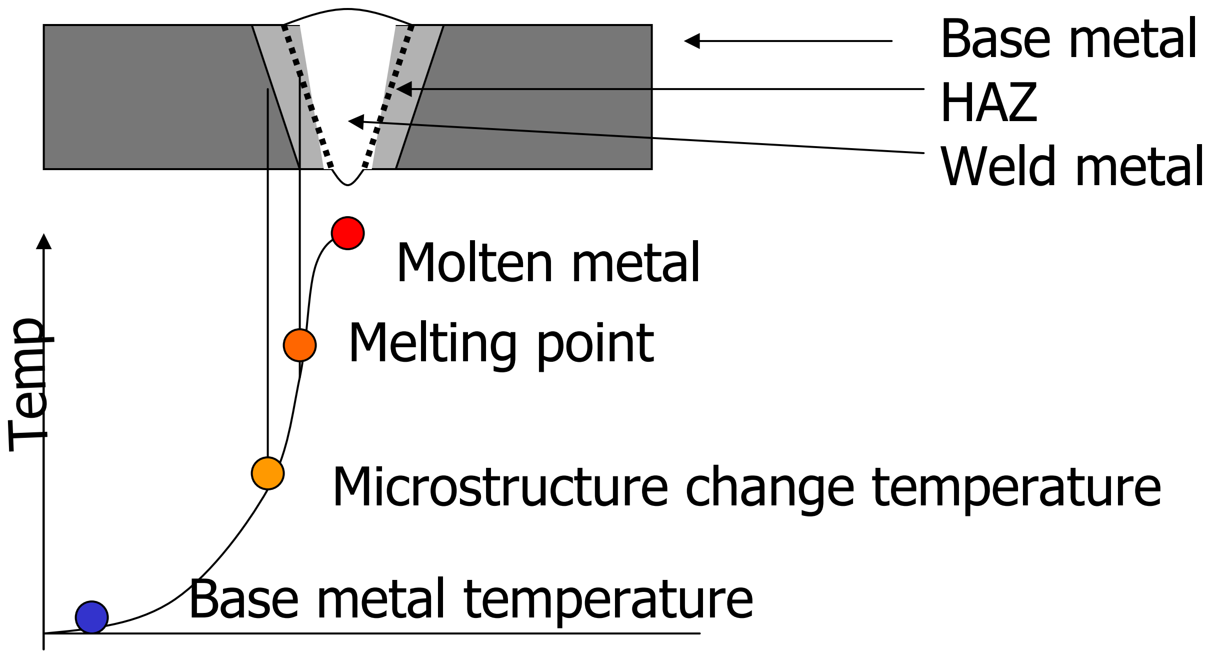
$$V_{weld} > \frac{d}{t_{\max}}$$

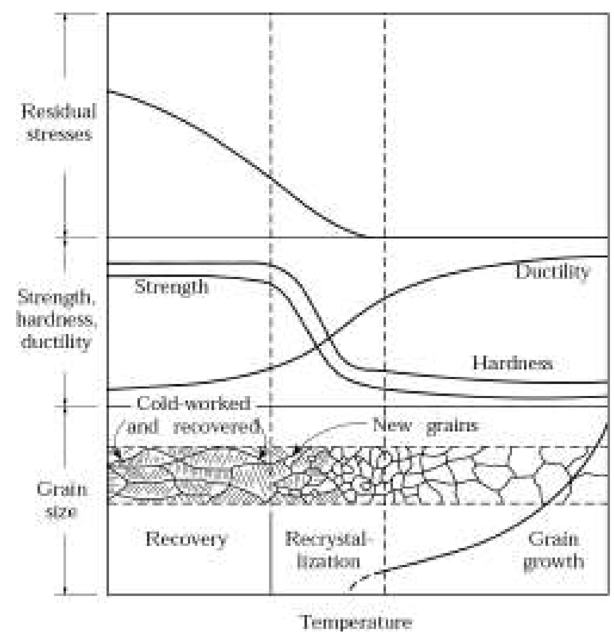
Weld Pool – Heat Source Interaction Time



HAZ(Heat Affected Zone)

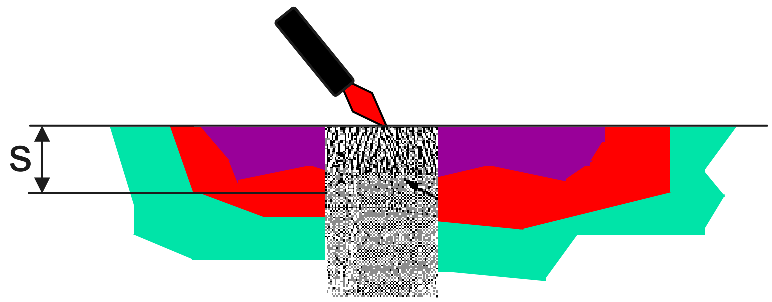
- Bad microstructure, course grains, weak to corrosion
- Plastic vs. Metal





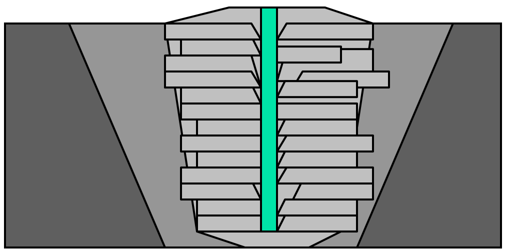
Heat Affected Zone

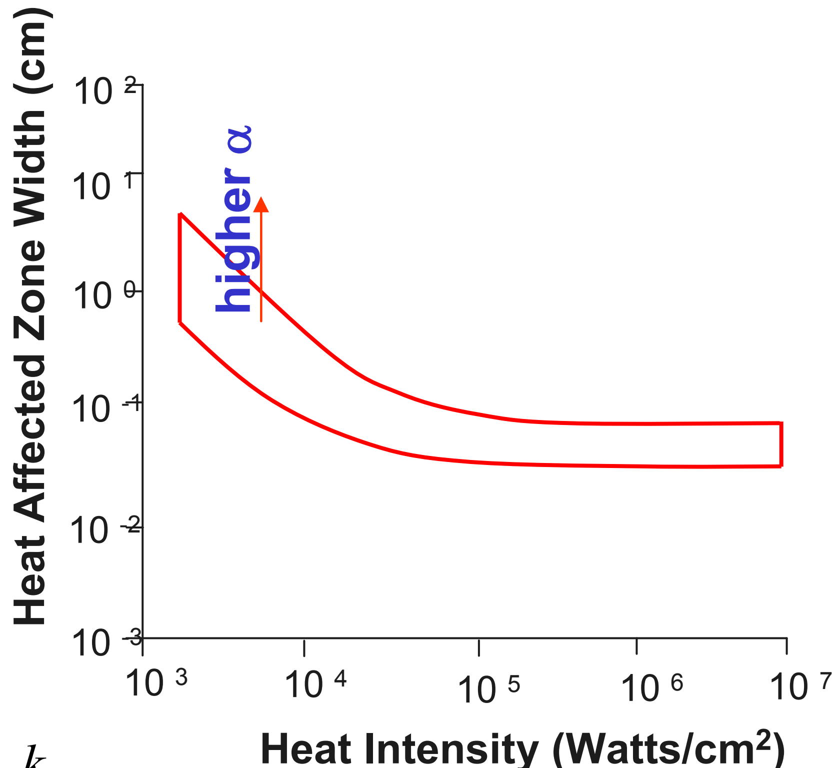
- Region near the weld pool is affected by heat. Microstructure changes.
- $s \sim (\alpha\ t)^{0.5}$



- The size of the heat affected zone is controlled by the thermal diffusivity, α: Al, Cu
- HI, time (speed)
- Metal vs. Plastic

Heat Affected Zone (HAZ)



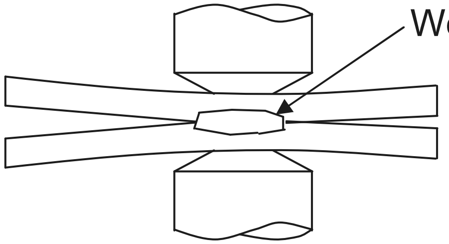


Grain structure
Weld line
Intergranular corrosion
recrystallization

$$\sigma_y = \sigma_o + \frac{k_y}{\sqrt{d_{grain}}}$$

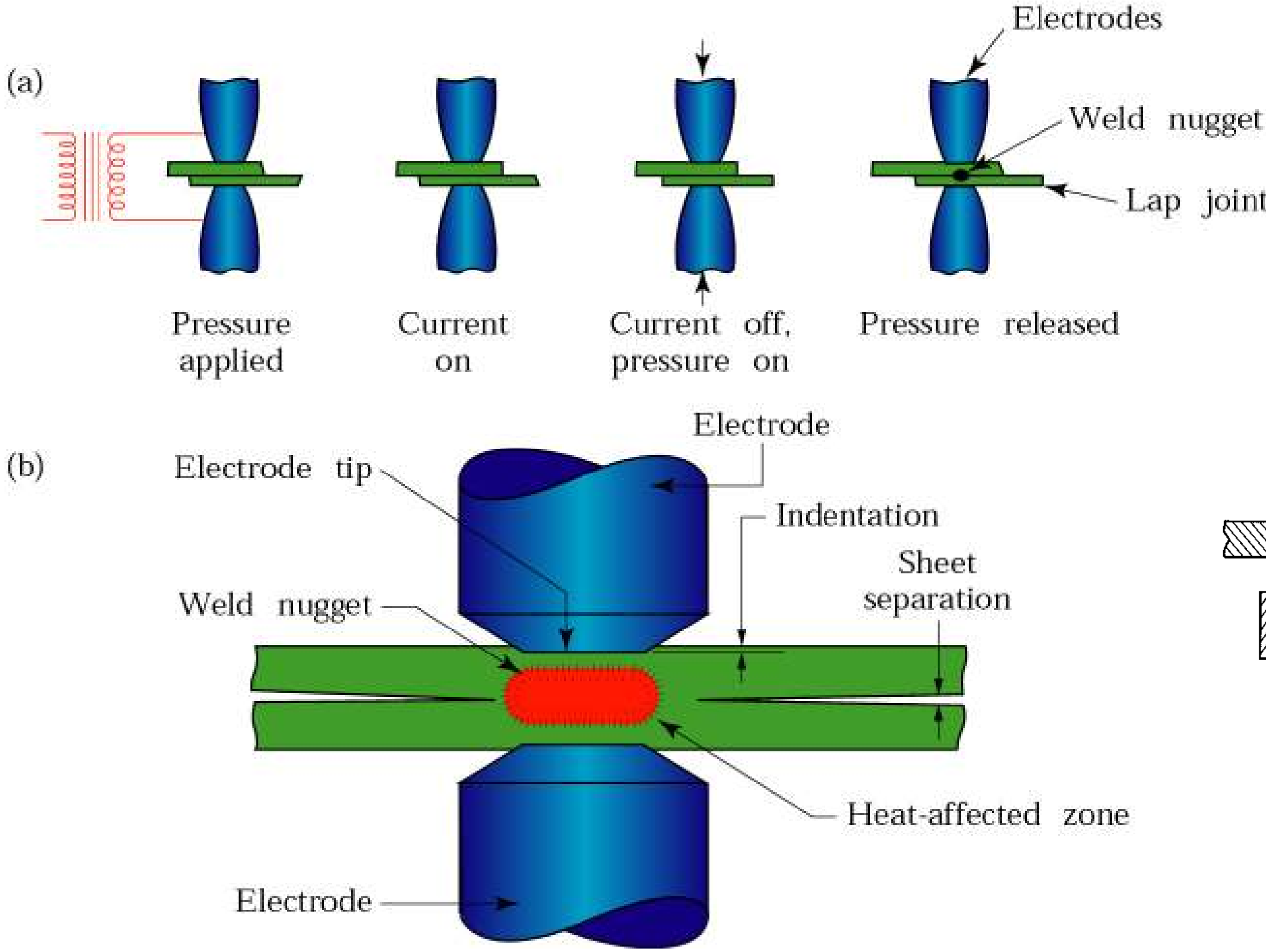
Resistance Welding

- Spot, seam, projection welding
- High current through the weld, 3000A-100,000A (0.5 – 10 V)

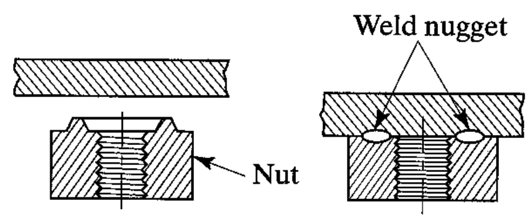


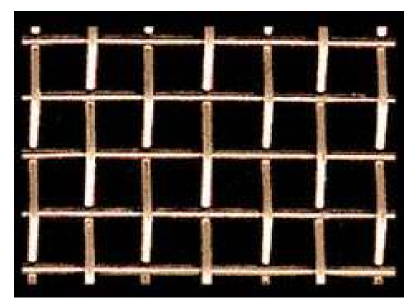
- Extremely high heat flux (10^5 W/cm^2)
- Heat generated: $H = I^2 R t K$ (K=efficiency)
- Ex: 5000 A, 0.1 sec flow, 5 mm dia electrodes, two 1mm thick steel plates
  - Effective resistance 200 $\mu\Omega$, Then H= 500 J
  - Nugget volume, 30 mm^3, mass 0.24 g, 1400 J/g needed to melt
  - 336 J for melting < 500 J

Spot Welding



Projection Welding





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Solid-state: interatomic bonding

- Ultrasonic
  - Oscillating tangential shear + static normal forces
  - 10KHz to 75 KHz
  - Shear → plastic deformation→ breaking up top layer (contaminated) → inter-atomic bond
- Friction
  - Rotational part (at least one), flash
- Diffusion
  - Goldsmiths bonded gold over copper
  - Diffusion T > 0.5 Tm
  - Interface is the same as the bulk.
  - Fuselage frames

Ultrasonic Welding

(a) (b)

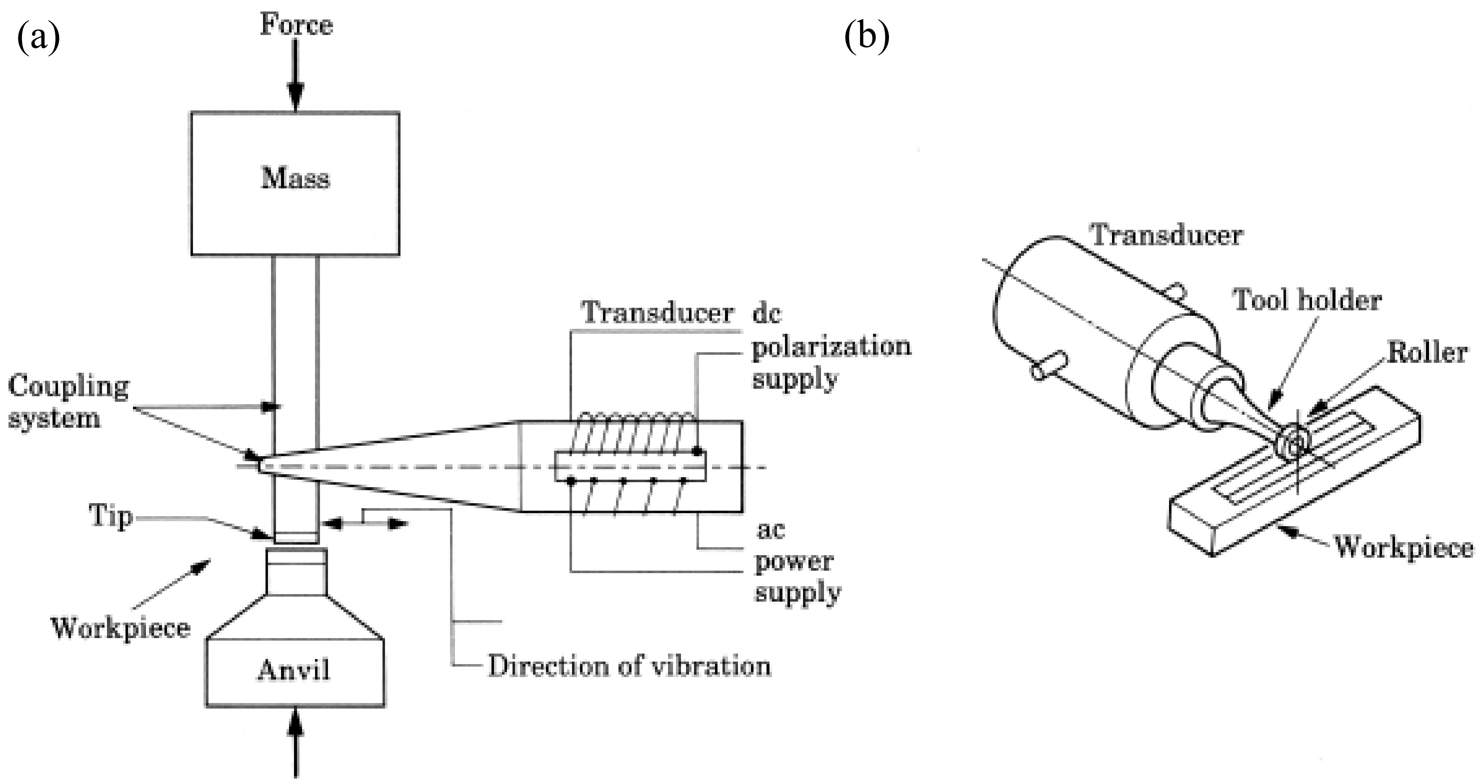


Figure 28.2 (a) Components of an ultrasonic welding machine for lap welds. The lateral vibrations of the tool tip cause plastic deformation and bonding at the interface of the workpieces. (b) Ultrasonic seam welding using a roller.

Friction Welding

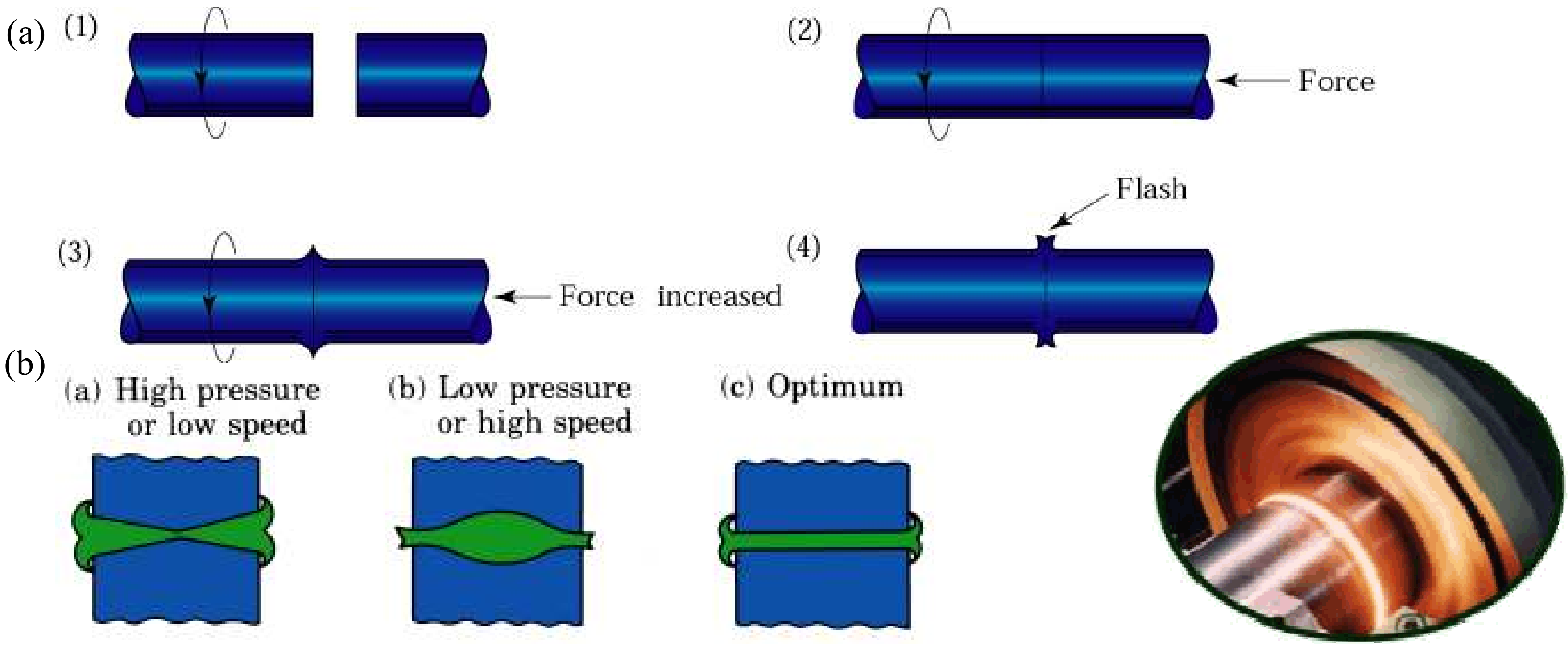
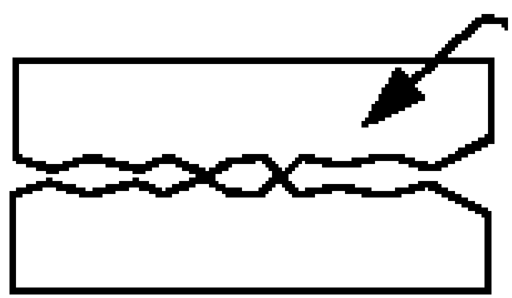


Figure 28.3 (a) Sequence of operations in the friction welding process: (1) Left-hand component is rotated at high speed. (2) Right-hand component is brought into contact under an axial force. (3) Axial force is increased; flash begins to form. (4) Left-hand component stops rotating; weld is completed. The flash can subsequently be removed by machining or grinding. (b) Shape of fusion zone in friction welding, as a function of the force applied and the rotational speed.

Diffusion bonding

- Filled Gold
- Diffusion bonding is often divided into three stages
  - Asperities + pressure = decreased interface porosity
  - Continued heating causes the porosities to shrink
  - Crystals grow across interface, some porosity may be trapped
- Time: Important variables/parameters:
  - Pressure = (500 to 5,000 psi) Temperature (0.5 T_{melt})
  - Surface finish Surface cleanliness
  - \$2000-4000/mm^2 equipment cost



Diffusion Bonding/Superplastic Forming

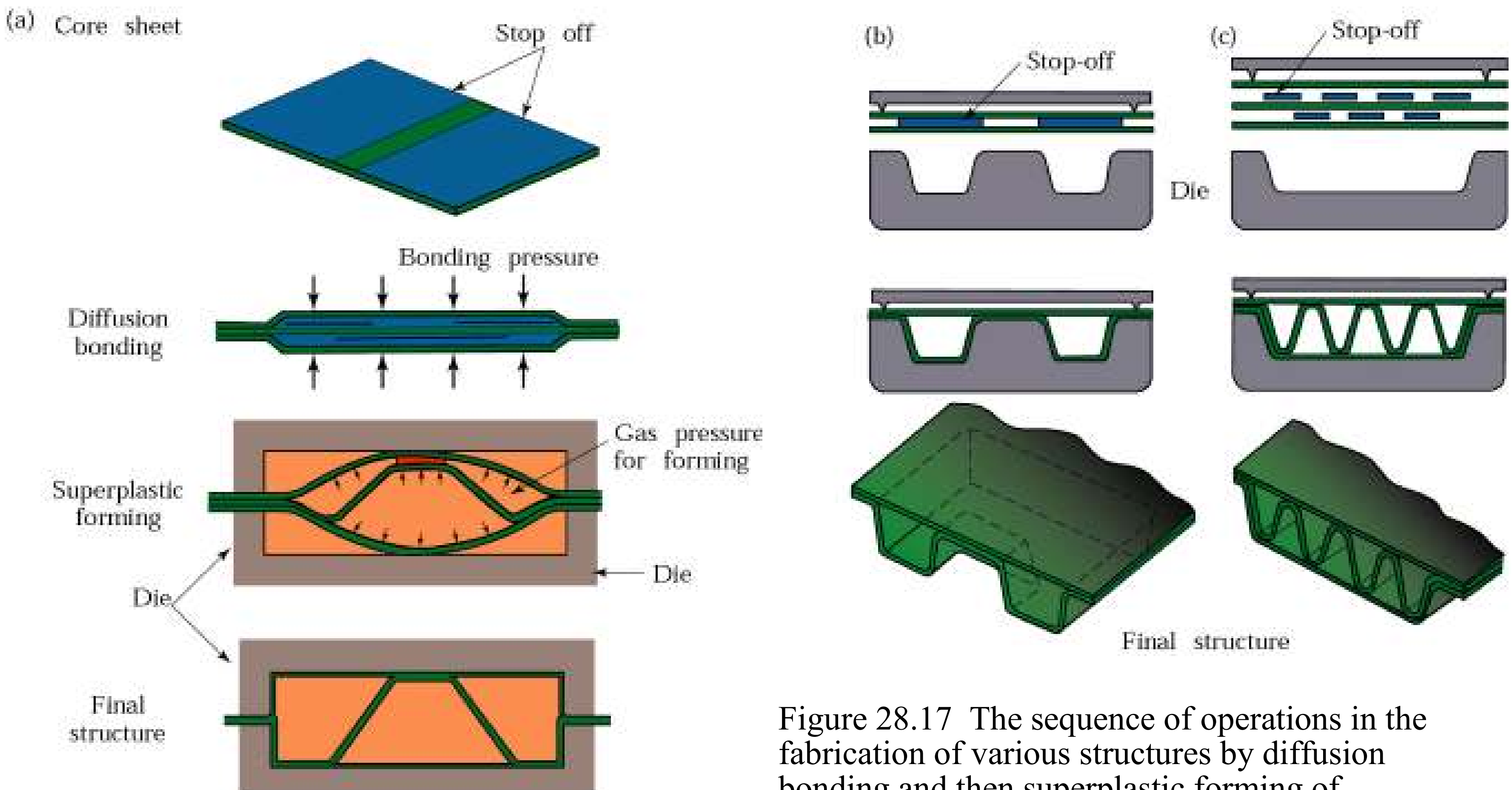


Figure 28.17 The sequence of operations in the fabrication of various structures by diffusion bonding and then superplastic forming of (originally) flat sheets. *Sources*: (a) After D. Stephen and S.J. Swadling. (b) and (c) Rockwell International Corp.

Diffusion Bonding Applications

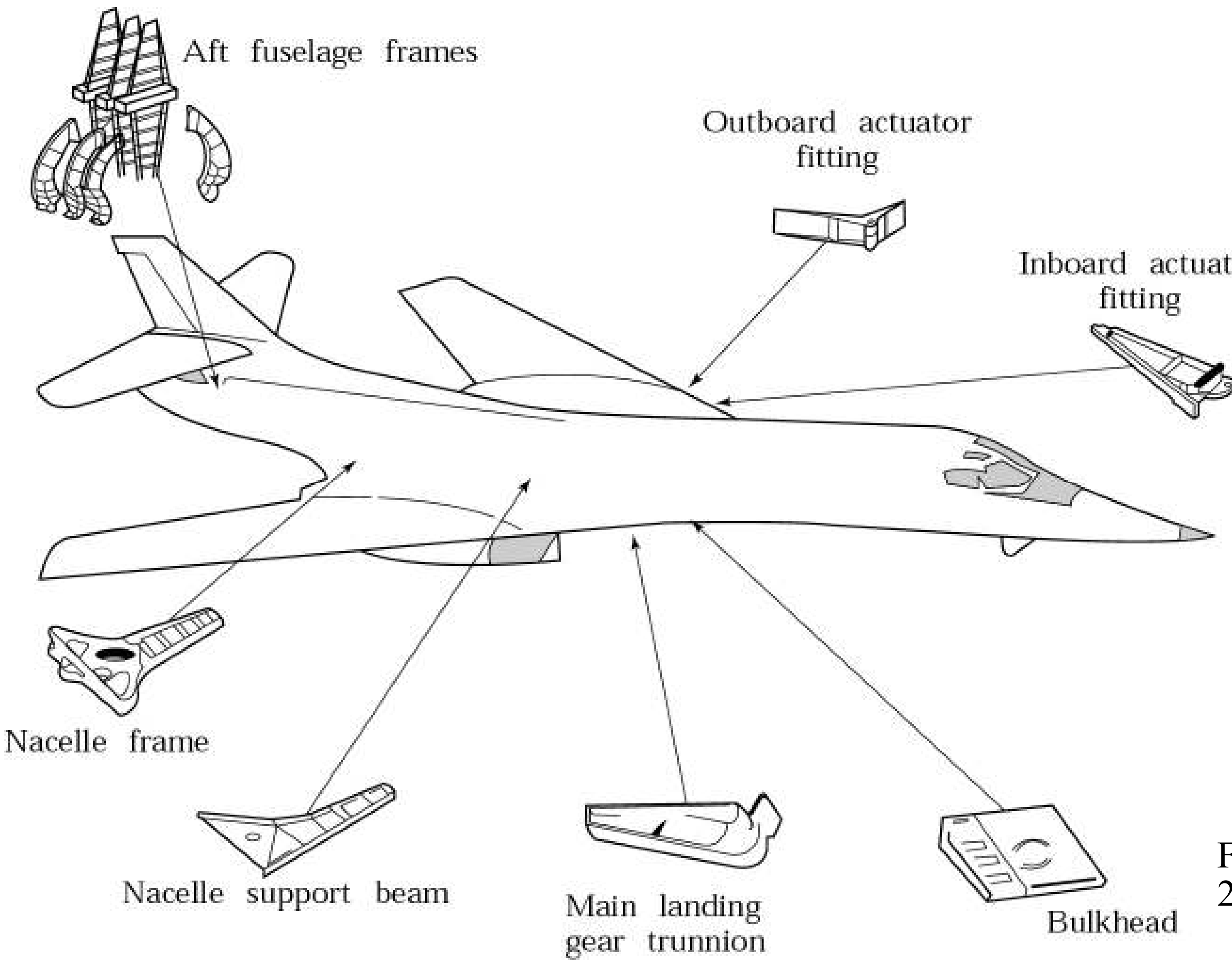
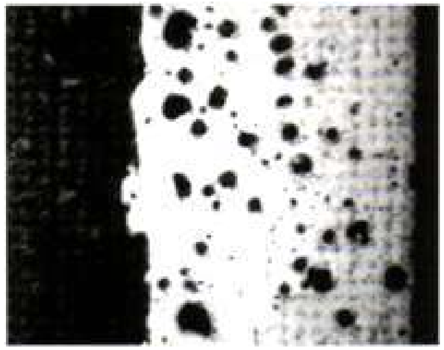


Figure 28.16

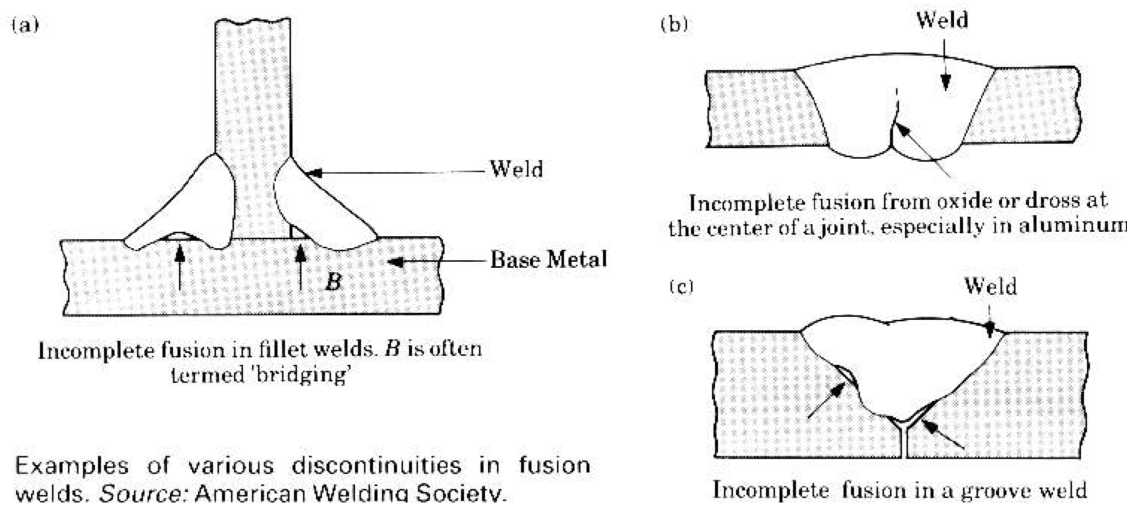
Weld quality and defects

- Porosity
  - Trapped gases, contaminants
  - Preheat or increase rate of heat input
  - Reduce speed allowing gas to escape, cleaning
- Slag inclusions
  - Oxides, fluxes, electrode coating trapped in weld zone
  - Clean weld bead during multi-weld processes
  - Provide enough shielding gas



Weld quality and defects

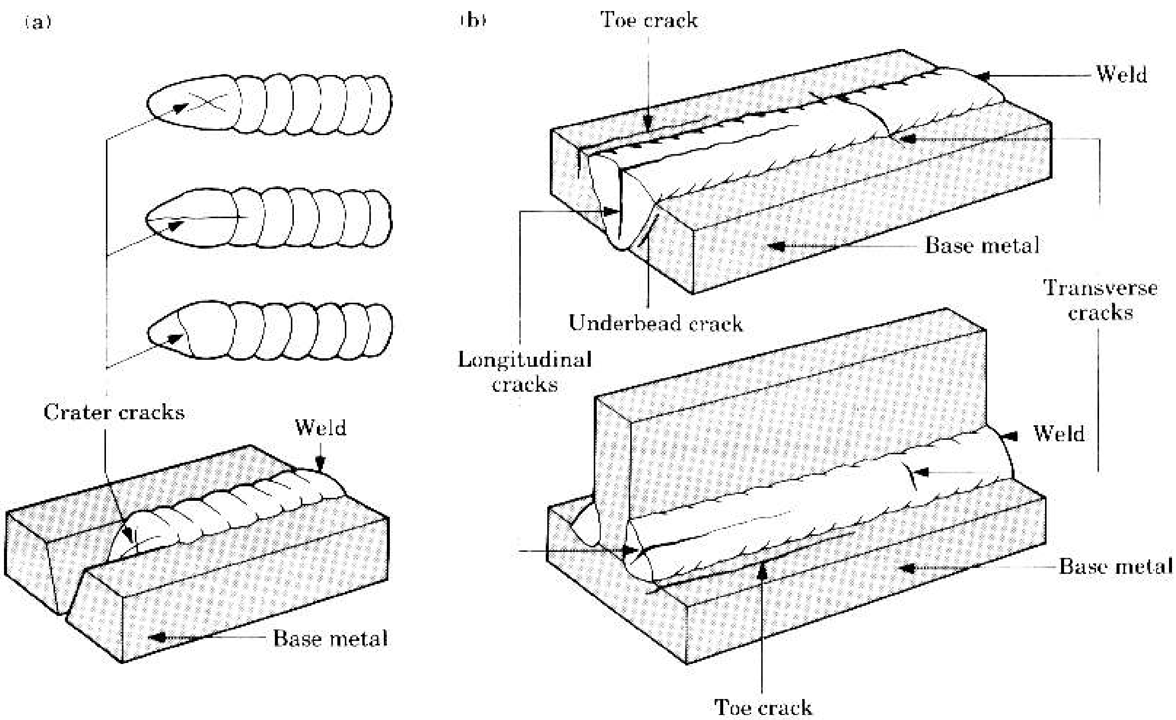
- Incomplete fusion/penetration
  - Preheat and clean joint
  - Clean weld area, enough shielding gas
  - Change joint design or type of electrode



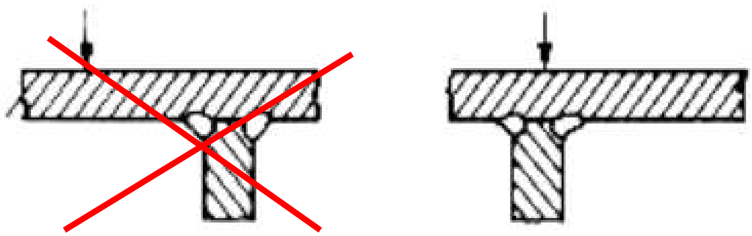
Examples of various discontinuities in fusion welds. *Source:* American Welding Society.

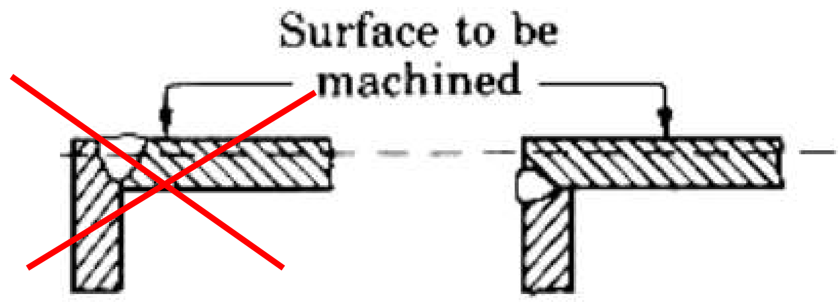
Weld quality and defects

- Cracks, residual stresses
  - Temperature gradients, embrittlement of grain boundaries
  - Inability of weld metal to contract during cooling

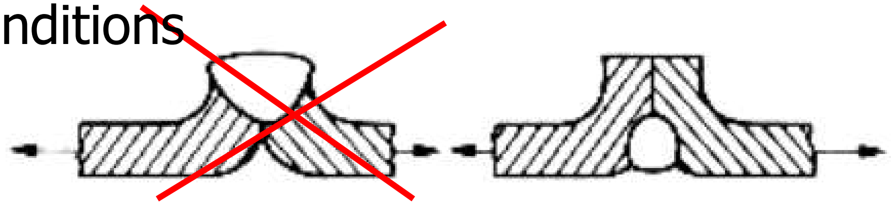


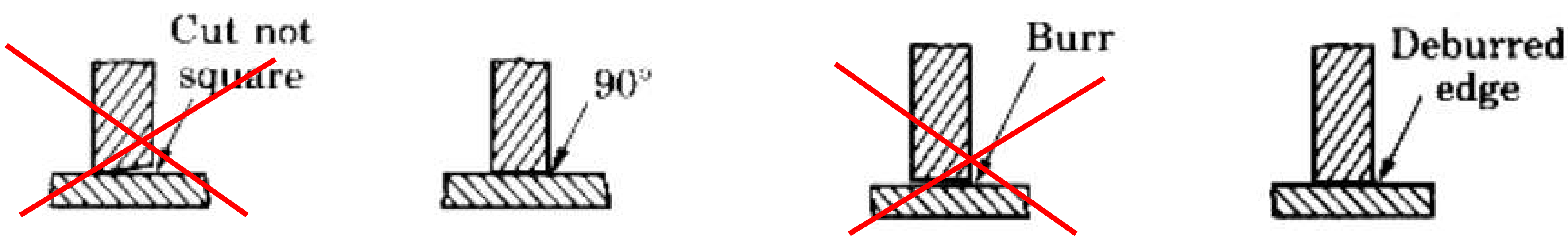
DFA - Welding



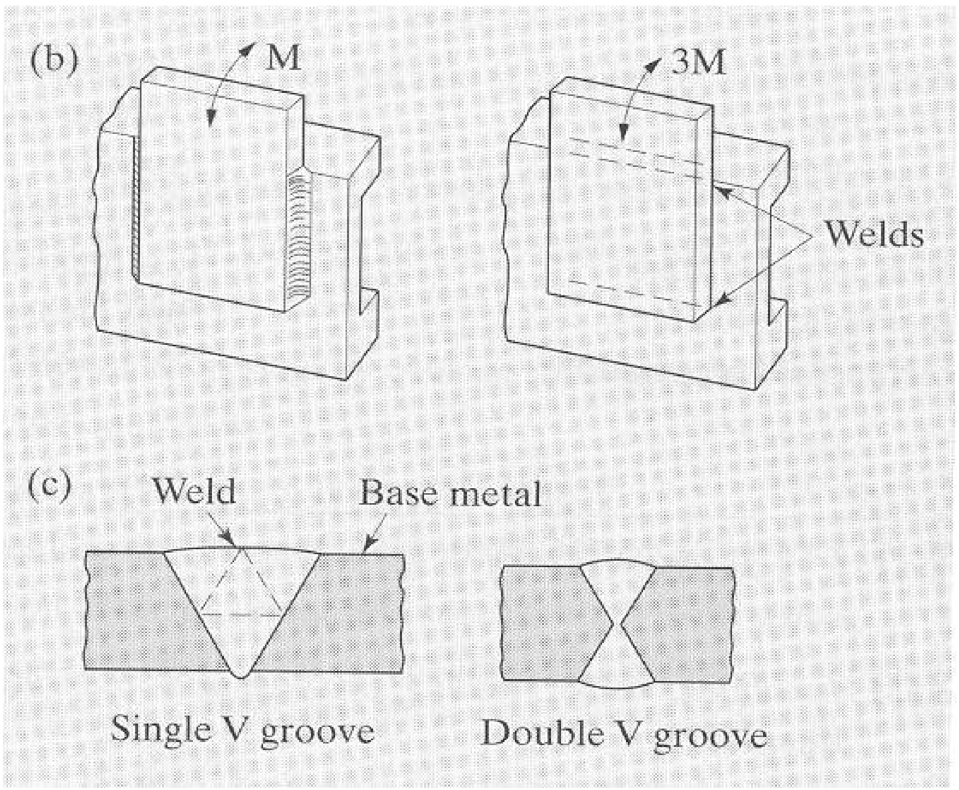


Loading conditions

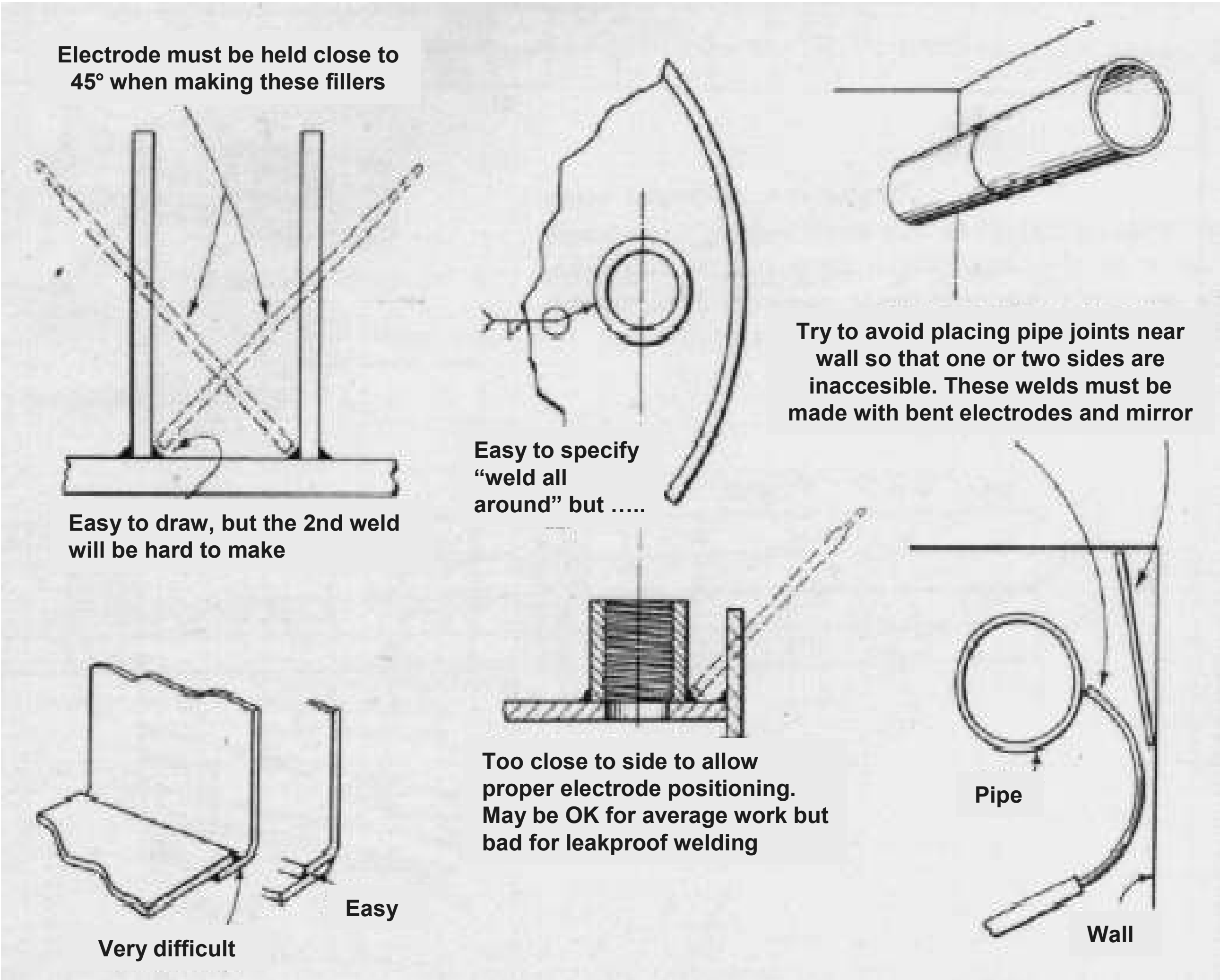




DFM welding



Welding accessibility, DFM



Cost - Joining

- Metal arc welding
  - Low tooling costs, moderate equipment costs
  - High direct labor costs
  - Economical for low production runs
- Resistance welding
  - Low tooling costs, high equipment costs
  - Low direct labor costs
  - Full automation can be easily formed
- Soldering / Brazing
  - Low tooling costs, various equipment costs depending on the automation level
  - Low to moderate direct labor costs
- Adhesive bonding
  - Low tooling costs, moderate equipment costs
  - Low direct labor costs

Quality - Joining

- Metal arc welding
    - Relatively moderate HAZ exists
    - Good surface finish
- Resistance welding
    - Clean, high quality welding with low distortion
    - Small HAZ
    - High strength welds are produced by flash welding
- Soldering / Brazing
    - Virtually stress and distortion free joints
    - Excellent surface finish
- Adhesive bonding
    - Excellent quality joints with virtually no distortion
    - Joint strength may deteriorate with time and sever environment conditions

Rate - Joining

- Metal arc welding
  - Economical for low production runs – manual welding
  - Well suited to traversing automated and robotic systems
- Resistance welding
  - High production rate is possible due to short weld times
  - Easy full automation
- Soldering / Brazing
  - High production rates are possible for dip soldering ex>Printed Circuit Boards
- Adhesive bonding
  - Low production runs

Flexibility - joining

- Metal arc welding
  - Generally high flexibility but depends on the automation level
- Resistance welding
  - Low flexibility due to high automation level
- Soldering / Brazing
  - Various level of automation is possible
- Adhesive bonding
  - Very flexible process
  - Can aid weight minimization in critical applications