

2.008 Design & Manufacturing II

Spring 2004

Welding & Joining

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S.Kim

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Today

- Ask "Dave and Pat"
- Joining & Welding
 - PP 771-861, Kalpakjian
- Quiz 1 on March 17th, 12:30 PM
 - Closed book, calculator
 - Lecture notes, HWs
 - Q&A session? March 15th, Monday, 5-6PM ?
 - HW# 4, due next Monday

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Joining

- Cost:
 - Cheap, but expensive labor
- Quality:
 - Wide range
- Flexibility:
 - Manual vs automated
- Rate:
 - Slow in general

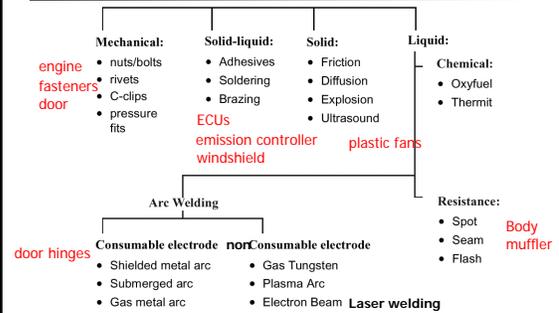


Very Large Crude Carrier (VLCC)

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Joining processes



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Mechanical Fastening

- Any shape and material almost
- Disassemblable (except Rivets, etc.)
- Least expensive for low volume (standardized)
- Problems: strength, seal, insertion, loosening



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Figures, B. Bernhabib

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Rivets

- Cheap, light weight, don't get loose
- Permanent, less strong than bolts
- Rule of thumb
 - Minimum spacing = 3 x d
 - Maximum spacing = 16 x thickness of the outer plate

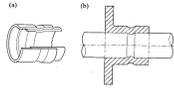


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Mechanical fastening

- Crimping
- Embossed protrusions
 - Plastic deformation / interference
 - Appliance
 - Automotive



Lego assembly, elastic averaging

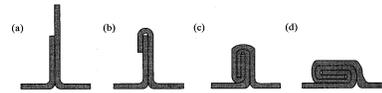
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M. Cuipepper, MIT

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Mechanical Joining

- Hemming, seaming
 - Bend edge of one component over another
 - Automobile door stampings and trunk lids

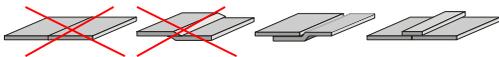


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Adhesive Bonding

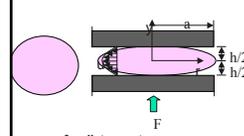
- Quick and non-invasive
- Most materials with high surface to volume ratio
- Insulation (thermal, electrical), conducting adhesives available
- Good damping
- Clean surface preparation
- Long curing, hold time, low service T
- Reliability, quality?
- Disassembly?



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Stefan Equation



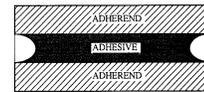
- Squeeze a drop of liquid
- h_r goes down, and
- Viscosity goes up (curing)
- Ft goes up (to separate)

$$p = \frac{3\mu}{h^3} \frac{dh}{dt} (r^2 - a^2)$$

$$Ft = \frac{3\mu\pi r^2}{4} \left[\frac{1}{h_r^2} - \frac{1}{h_i^2} \right]$$

When pullin apart?

$$Ft = \frac{3\mu\pi r^2}{4} \left[\frac{1}{h_r^2} - \frac{1}{h_i^2} \right]$$

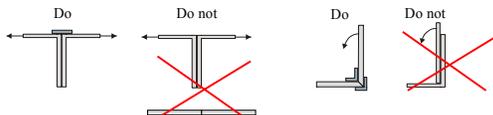


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DFA for bonding

- Weak to tensile loading, strong to shear and compressive
- Organic
 - Epoxy, acrylic, etc..
- Inorganic
 - solder, cement, etc..

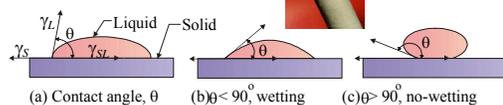


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Solid-Liquid: Brazing and Soldering

- In brazing, the filler material (silver, brass, bronze) has a melting point above 425 °C; and, in soldering, the filler material (lead, tin) has a melting point well below 425 °C.
- Capillary forces for the wetting and flow of the liquid metal into the gaps.
- Proper fluxes for lowering surface tension, remove oxides, and prevent oxidation.



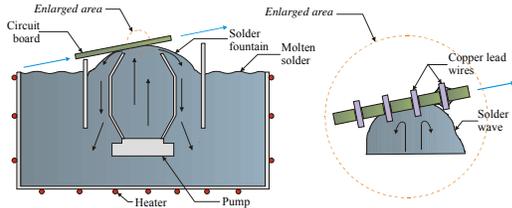
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B. Benhabib

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Wave soldering

- Exposed metal joints are passed over a wave in a continuous motion, where liquid solder penetrates into the joint by capillary forces:



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Welding

- Solid-state welding
 - No liquid, electrical, chemical, mechanical
 - Resistance, diffusion, ultrasonic
- Fusion welding
 - Chemical: Oxyfuel
 - Electrical: Arc welding
 - Consumable electrode
 - Non-consumable electrode

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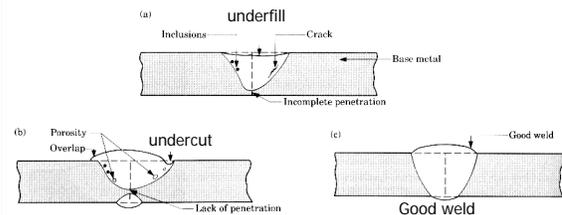
Fusion Welding

- Heat source: chemical, electrical
- Heat intensity
 - Control:
 - Incomplete fusion, penetration
 - Underfilling, undercutting, cracks
 - Heat affected zone (HAZ)
 - Feed rate

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Underfill and undercut

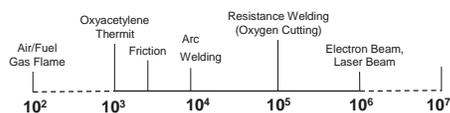


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Heat Intensity

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



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

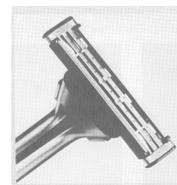
$$t_m = (5000/H.I.)^2$$

Oxy: 20-30 sec, E-beam: μ sec

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Laser for Razor



-500 μ m spots
-3 million spots per hour

How fast the welding speed is required?

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Kalpakistan

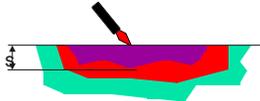
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Melting front speed 2D simplification

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

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

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

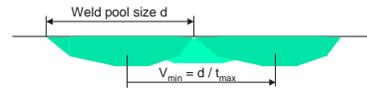


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Welding speed

- $t_m = (s_m)^2 / (2 \alpha J_a)$,
- Any longer, over-melt!

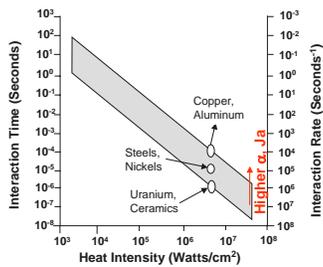


- If the weld pool size is d in diameter, then you must feed at a rate that exceeds d/t_{max} .
- HI increases, welding speed must go up
- α increases, interaction time must go up

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Weld Pool – Heat Source Interaction Time



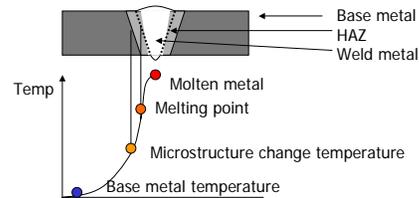
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J. Chun

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HAZ(Heat Affected Zone)

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



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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

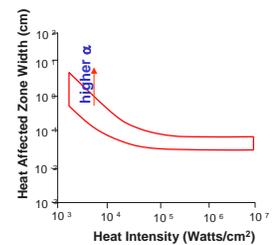
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Heat Affected Zone (HAZ)



Grain structure
Weld line
Intergranular corrosion
recrystallization

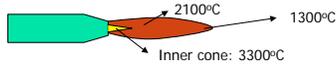
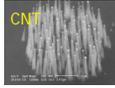


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Oxyfuel Gas Welding

- Low cost, manual
- Oxyfuel: Oxygen + Fuel (Acetylene, methacetylene-propediene, etc): can reach 3300°C
- Stoichiometry: neutral flame
 - $C_2H_2 + O_2 \Rightarrow 2CO + H_2 + \text{Heat} \uparrow$
 - $2CO + H_2 + 1.5O_2 \Rightarrow 2CO_2 + H_2O + \text{Heat} \uparrow$
- More oxygen will cause oxidization (Oxidizing flame): bad for steels, OK for copper
- More fuel will cause carburization (carburizing flame): Low heat for brazing, soldering, flame hardening

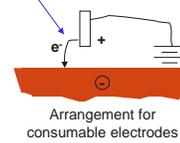


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Arc fusion welding

- Temperature up to 30000°C
- Heat travels with the electrons!
- Straight polarity: workpiece +, electrode -
 - Shallow penetration, sheet metal, wide gaps
- reverse polarity
 - Deeper penetration



Heat generated at anode is about 15% of the heat generated at cathode.

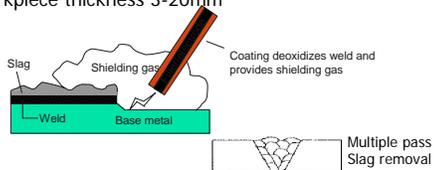
E_{electron} at cathode is given by three components:
 $I(\phi + V_a + V_{\text{thomson}})$
 ↑ Kinetic energy
 ↑ Drop across cool gas boundary
 Work function(heat of condensation)

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Consumable electrode processes

- Shielded metal arc welding
 - Cheapest and most basic process < \$1,500
 - 50A-300A, <10KW
 - Workpiece thickness 3-20mm



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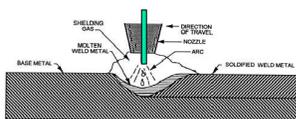
Fusion Arc Welding

- Preventing oxidation is the most important problem.
- Coated electrodes to provide shielding gas
 - Coatings: fluorides, silicate binders(clay), cellulose, carbonates
 - Electrodes: different materials such as mild steel.
- Submerged arc welding: covered by granular flux
 - Flat surfaces, high throughput, good quality
- Inert gas from external source
 - Gas metal arc welding (MIG)
 - Flux-cored arc welding, etc. (very versatile with proper fluxes)

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Gas Metal Arc Welding



Gas metal arc welding is a special variation on arc welding in which the electrode filler metal is fed directly through the torch tip. As arcing occurs the electrode instantly melts, forming molten droplets that fall into the weld pool. Shielding gas is supplied through the torch tip to prevent chemical interactions with the surrounding atmosphere

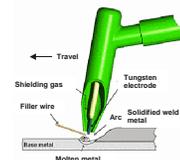
- Metal transfer
- Spray transfer
 - Globular transfer
 - Short circuiting

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Non-consumable electrode welding Gas Tungsten Arc Welding

- Gas tungsten arc welding, formerly known as TIG welding
- Tungsten electrode + filler wire.
- Good for thin materials, better control, Al, Mg, Ti, etc
- High quality and finish
- Tungsten electrode contamination
- 200A DC-500A AC, 8kW-50kW

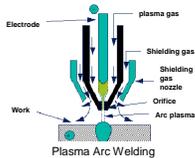


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Other non-consumable electrode processes

- Plasma arc welding:
 - very higher energy concentration (33000°C), high feed rate 120-1000 mm/min, arc stability, less thermal distortion, deep penetration (keyhole technology)
- Laser beam welding, electron beam welding, etc

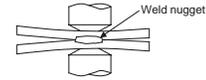


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Resistance Welding

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



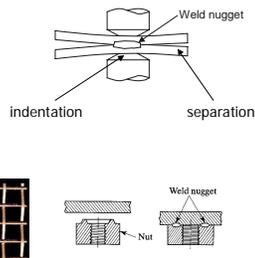
- Extremely high heat flux (10^5 W/cm²)
- Heat generated: $H = i^2 R t K$ (K=efficiency)
- Ex: 5000 A, 5 mm dia electrodes, two 1mm thick steel plates
 - Effective resistance 200 Ω , Then $H = 500$ J
 - Nugget volume, 30 mm³, mass 0.24 g, 1400 J/g needed to melt
 - 336 J for melting < 500 J

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Resistance welding

- Spot welding Sequence
 - Pressure on
 - Current on
 - Current off
 - Pressure off
- Projection welding



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Solid-state: interatomic bonding

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

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Weld quality and defects

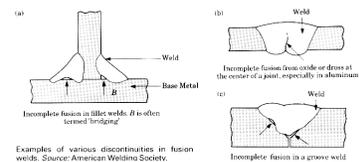
- Porosity
 - Trapped gases, contaminants
 - Preheat or increase rate of heat input
 - Reduce speed allowing gas to escape, cleaning
- Slag inclusions
 - Oxides, fluxes, electrode coating trapped in weld zone
 - Clean weld bead during multi-weld processes
 - Provide enough shielding gas

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Weld quality and defects

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

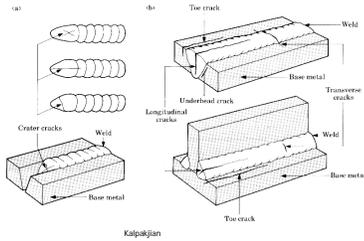


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Weld quality and defects

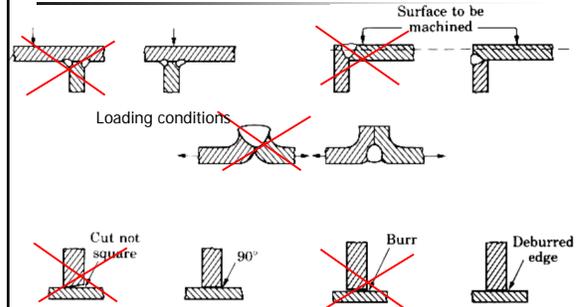
- Cracks, residual stresses
 - Temperature gradients, embrittlement of grain boundaries
 - Inability of weld metal to contract during cooling



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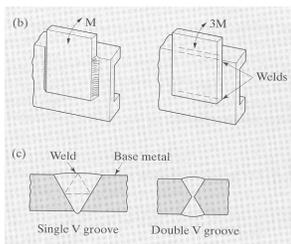
DFA - Welding



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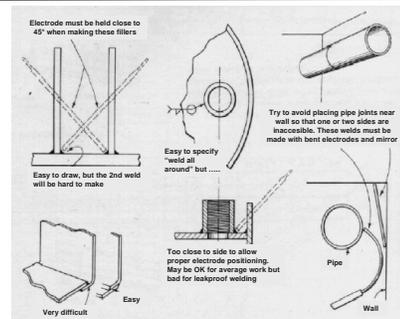
DFM welding



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Welding accessibility, DFM



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