Assembly and Joining

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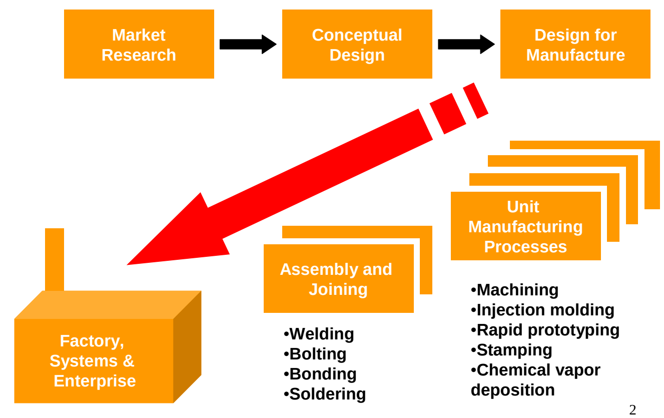
Manufacture



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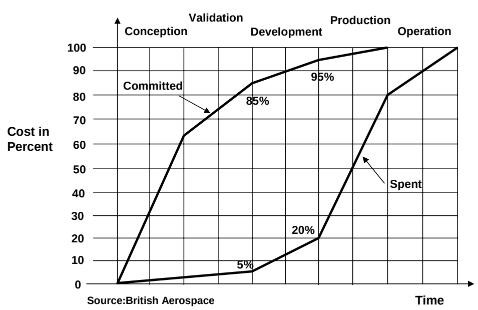
Impact of Design on Product Cost



The majority of cost commitment is made early in the product design cycle

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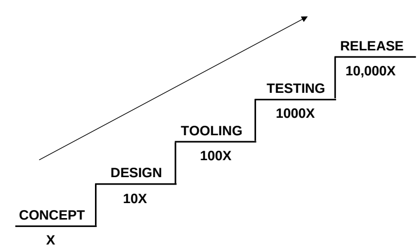
Cost of Design Changes



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"The best design is the simplest one that works"

Albert Einstein

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Assembly and Joining

- Assembly as a mfg process
  - Process components
  - Cost, Quality, Rate and Flexibility
- Specific joining processes
  - Mechanical
  - Adhesives
  - Solder and brazing
  - Cold welding
  - Fusion welding

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Assembly statistics

Industry	% Workers in Assembly
Automobile	45.6%
Aircraft	25.6%
Telephone & Telegraph	58.9%
Farm Machinery	20.1%
Home appliances	32.1%
Two-wheel vehicles	26.3%

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Justifying the need/type of assembly

- For assembly
  - Can't be made in one piece
  - Functional (bushings, bearings)
  - Manufacturability
  - Repair and maintenance
  - Transport: Does it fit in a plane?
- Against assembly
  - Defects that occur at interfaces
  - Loss of stiffness
  - Time & effort
  - Labor costs
  - Size

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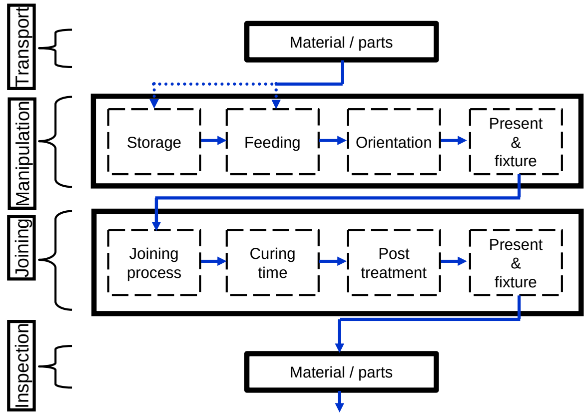
Rough assembly process diagram



Manual vs Automatic Assembly

- Manual assembly
  - Dexterity
  - Time (small run, urgent)
  - Complexity
- Automatic assembly
  - Precision
  - Load
  - Time
- What is important
  - Minimize parts
  - Ergonomics
  - Cost
  - Training
  - Reliability

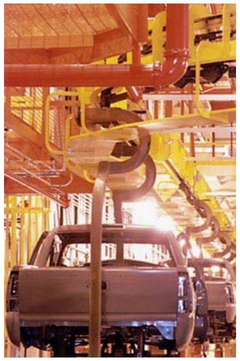
PART TRANSPORT, ORIENATION AND FEEDING

Part handling and feeding

- Moving parts between processing stations
- Control amount delivered
- Control spacing and frequency of delivery
- Robust with respect to tangling and jamming

Part transport: Overhead

http://www.tegopi.pt/pt/novidades/images/25-10-2000.jpg



http://accosystems.com/autoclient%20(2).jpg

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Part transport: Conveyor

http://www.ssiconveyors.com/pics/

http://www.ssiconveyors.com/pics/

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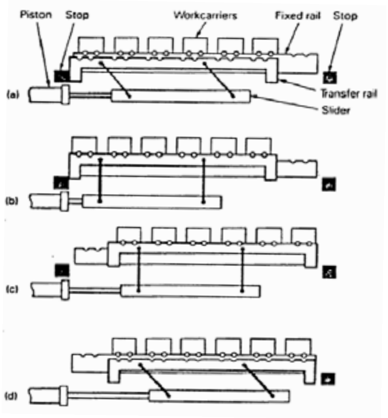
Part transport: Transfer line



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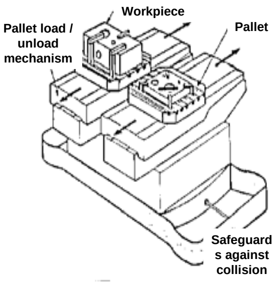
AGV



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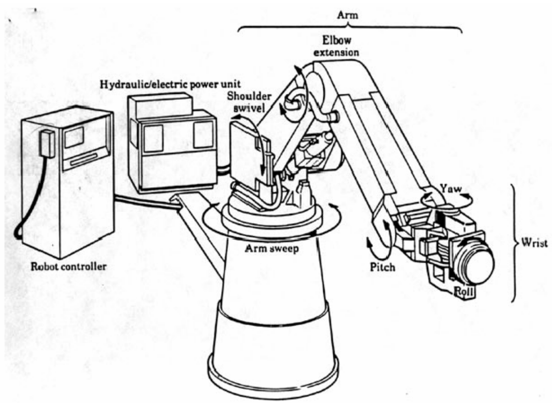
Part feeding and orientation



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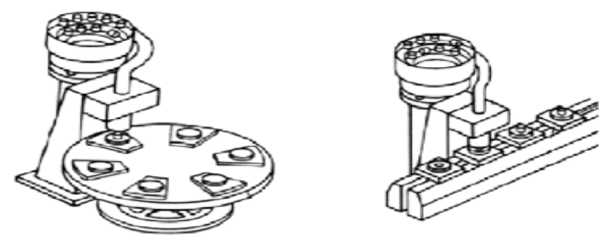
Part feeding and orientation



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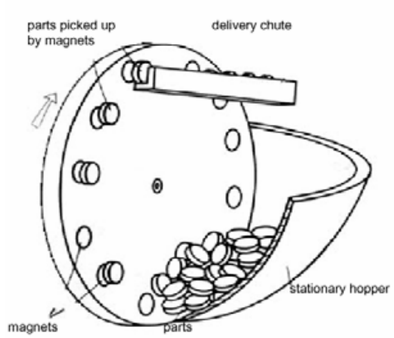
Part feeding and orientation



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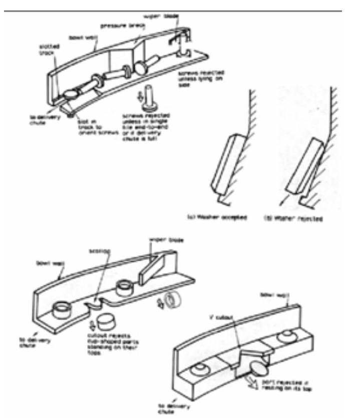
Part feeding and orientation



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Guidelines to Good Design-for-Assembly

- Minimize the number of parts
- Design assembly process in a layered fashion
- Consider ease of part handling
- Utilize optimum attachment methods
- Consider ease of alignment and insertion
- Avoid design features that require adjustments

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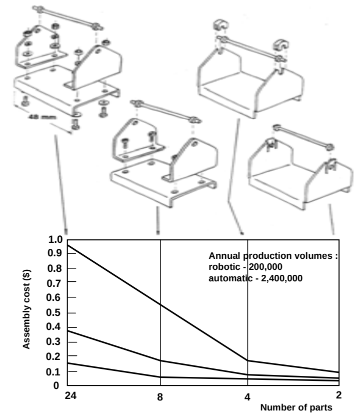
DFA - Example

Minimize the number of parts



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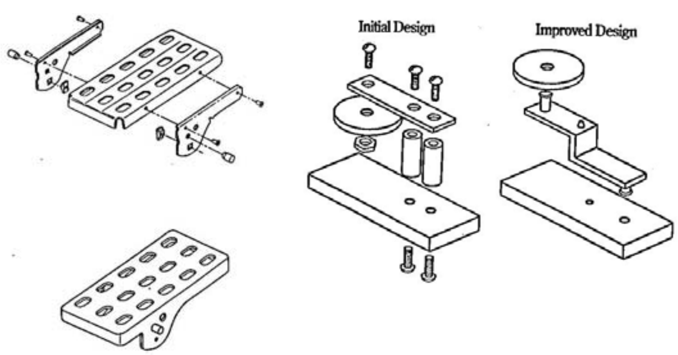
DFA - Example

Minimize the number of parts



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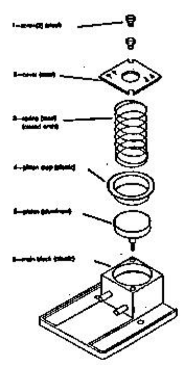
DFA - Example

Design assembly process in a layered fashion



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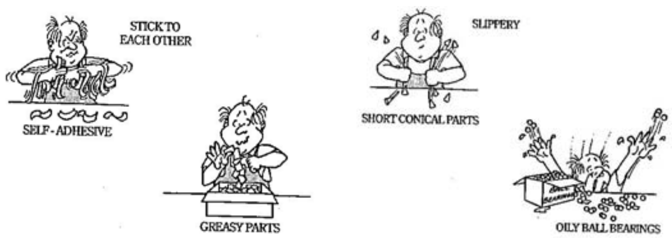
DFA - Example

Consider ease of part handling



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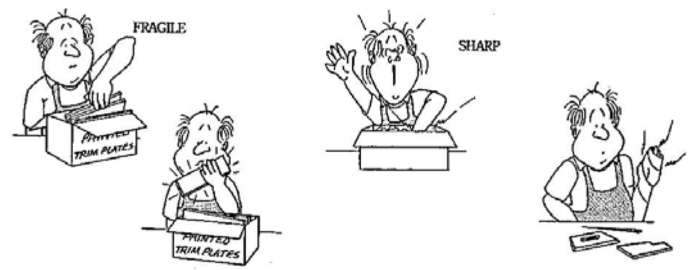
DFA - Example

Consider ease of part handling



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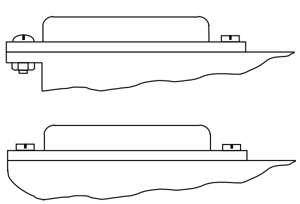
DFA - Example

Utilize optimum attachment methods



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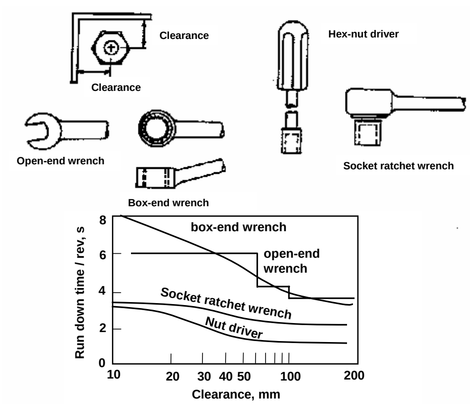
DFA - Example

Utilize optimum attachment methods



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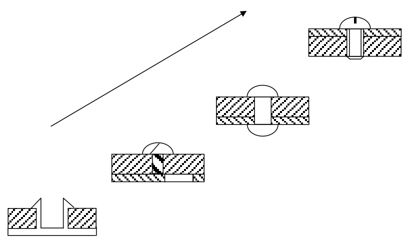
DFA - Example

Utilize optimum attachment methods



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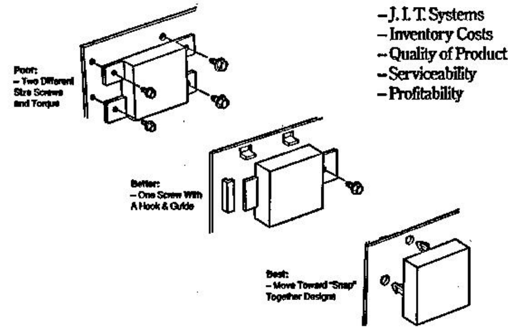
DFA - Example

Utilize optimum attachment methods



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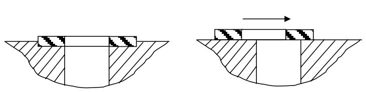
DFA - Example

Consider ease of alignment and insertion

- Design parts to maintain location



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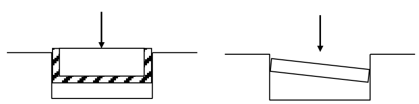
DFA - Example

Consider ease of alignment and insertion

- Mating parts should be easy to align and insert



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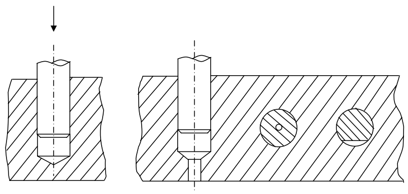
DFA - Example

Consider ease of alignment and insertion



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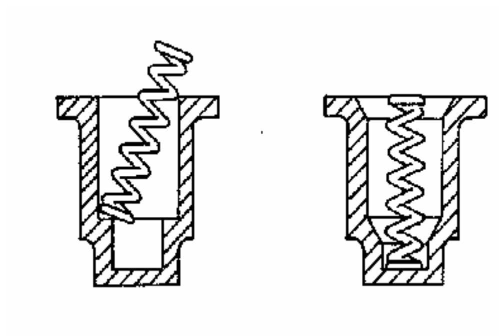
DFA - Example

Avoid design features that require adjustments



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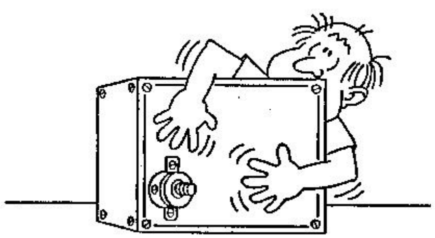
DFA - Example

Avoid restricted vision



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DFA - Example

Avoid obstructed access

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Joining

- Assembly cost often account for more than 50%
- Joining processes
  - High scrap cost
  - Failure spot

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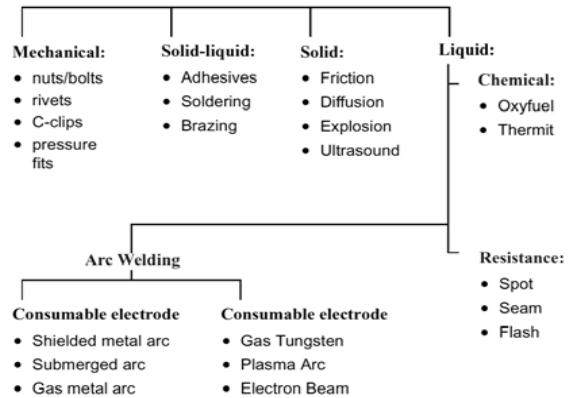
Joining processes/types



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Selection Criteria

- Geometry
- Material type
- Value of end product
- Size of product run
- Availability of joining method

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MECHANICAL JOINING

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Mechanical Fastening

- Any shape and material
- Semi-permanent
- Least expensive for low volume (standardized)
- Problems: strength, seal, extra part, assembly, loosen

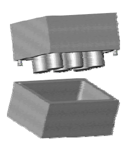
Fasteners

- Bolts/screws
  - Good for disassembly and reassembly
  - Cross threading can be a problem
- Rivets
  - Used when disassembly is not required
- Dowel pins
- Cotter pins
- Snap fits

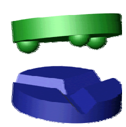
Common alignment mechanisms

Relative cost:
$ = low cost
$$ = moderate cost
$$$ = expensive

Elastic Averaging
Non-Deterministic



Pinned Joints
No Unique Position

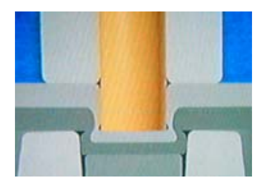


Exact constraint
Kinematic Constraint

Contaminants:	Sensitive	Contaminants:	Insensitive	Contaminants:	Insensitive
Load capacity:	High	Load capacity:	Low - High	Load capacity:	Low - High
Wear in:	Long	Wear in:	No	Wear in:	Short
Exact constraint:	No	Exact constraint:	No	Exact constraint:	Yes
Cost:	$$$	Cost:	$ <-> $$$	Cost:	$$
Complexity:	Simple	Complexity:	Simple	Complexity:	Moderate
Common: Yes		Common: Yes		Common:	No
Repeatability ~	5 micron after wear in	Repeatability ~	25 micron at best	Repeatability ~	¼ micron is common

Embossing and hemming

- Embossed protrusions
  - Plastic deformation / interference
  - Appliances
  - Automotive
  - Furniture
- Hemming
  - Bend edge of one component over another
  - Automobile doors



Press fits

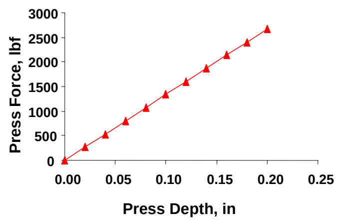
δ = radial interference
E = Young's modulus
p = interface pressure

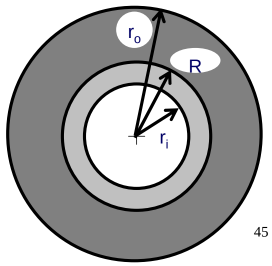
α = Coefficient of thermal expansion
ΔT = Temperature change

$$p = \frac{E}{R}\cdot\delta\cdot\left[\frac{\left(r^2{}_o - R^2\right)\cdot\left(R^2 - r^2{}_i\right)}{2\cdot R^2\cdot\left(r^2{}_o - r^2{}_i\right)}\right] \longrightarrow F_{insert} = \mu\cdot p\cdot 2\cdot\pi\cdot R\cdot x_{insert}$$

$$\delta_{thermal} = \alpha\cdot R\cdot\Delta T$$

Insertion force for press fit





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ADHESIVE JOINING

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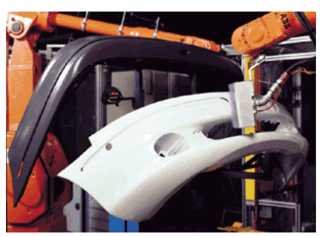
Example – Adhesive Bonding



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Adhesive joining

- Advantages
  - Different materials, Easily automated, Damp /seal
- Limitations
  - Time, Preparation/curing, Loading
- Important properties/characteristics of adhesives
  - Strength, Chemically inert, Compatibility

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Adhesive Bonding

- Quick, non-invasive, inexpensive
- Low stress
- Variety of materials
- Seal
- Low part count
- Temperature-limited
- Long set time
- Surface preparation
- Reliability/disassembly
- Best for components with high surface to volume ratio

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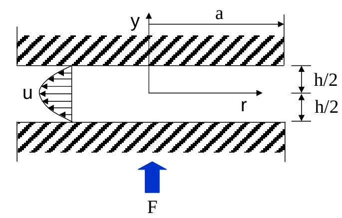
Stefan Equation



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

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What does Stephan equation mean?

$$F \cdot t_{final} \approx \frac{3 \cdot \mu \cdot \pi \cdot a^4}{4} \cdot \left(\frac{1}{h_{final}^2}\right)$$

Viscosity: **Start with low μ & finish with high μ**

Gap: **Small assembled gap**

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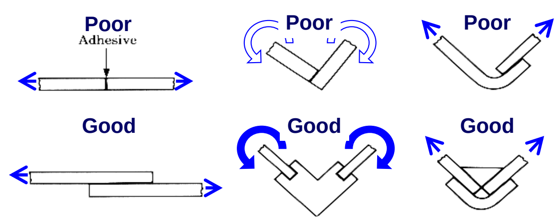
DFM with adhesives

- What is important
  - Matching type of loading to the design (shear/tension vs. peeling)
  - Maximizing contact area



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BRAZING
&
SOLDERING

Example – Brazing / Soldering

Soldering/Brazing

- Capillary
- Shear strength
- Temperature limit
  - Soldering : < 450 degree : Lead, Tin
  - Brazing : > 450 degree: Silver, Brass, Bronze
- Substrate phase stays solid : can be used on dissimilar metals
- Used in electronics, plumbing, jewelry, and recently, as a structural joining

Soldering & brazing

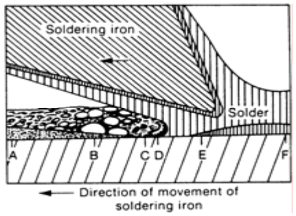
- Brazing: T > 450^{o} C
  - Brazes: Silver, Brass, Bronze

- Soldering: T < 450^{o} C
  - Low temps require fluxes
  - Solders: Lead, Tin, Bismuth

- Processes
  - Torch: Oxyacetylene torch and filler metal
  - Furnace: Lay filler around joint and send into furnace
  - Induction: Heat part by induction
  - Resistance: Heat part by contact/current

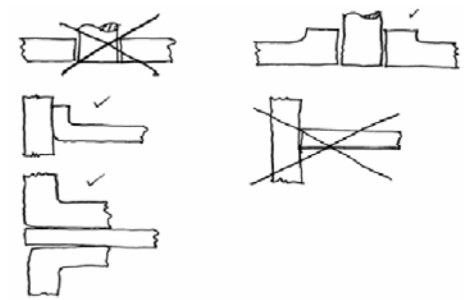
Anatomy of solder/brazing process

- Purpose of fluxes
  - Remove oxides
  - Protect from oxidization
  - Improve surface wetting
- Process
  - A. Flux on top of oxidized metal
  - B. Boiling flux removes oxide
  - C. Base metal in contact with molten flux
  - D. Molten solder displaces molten flux
  - E. Solder adheres to base metal
  - F. Solder solidifies



DFA for Soldering and Brazing

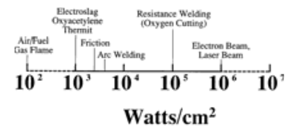
- Provide large surface area contact
- Filler metal should have good wetting characteristics (capillary action)
- Joined surfaces should not be smooth



COLD WELDING (Interatomic) PROCESSES

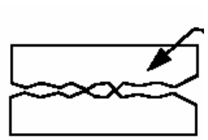
Ultrasonic and friction welding

- Ultrasonic welding (shear @ 10 to 75kHz vibration)
  - Contamination is redistributed, not displaced
  - Example: Wires/connectors in electronics components
- Friction welding
  - Material surfaces sheared against each other
  - Some metal extrudes out of weld zone, removes contaminates



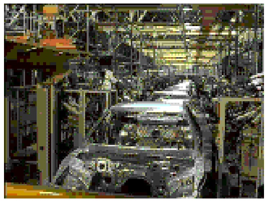
Diffusion bonding

- 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 ($^2/_3$ T_{melt})
  - Surface finish Surface cleanliness



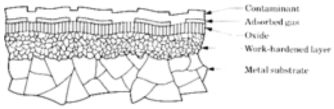
FUSION WELDING PHYSICS

Example – Spot Welding



Fusion welding

- Process of fusing two materials to join them
- Challenges in fusion welding
  - Disrupting oxide layers and contamination



  - Achieving high % surface area contact

Welding

- Heat source
- Heat intensity
  - Control (overmelting/evaporation)
  - Heat affected zone (HAZ)
  - Efficiency
  - Depth/width ratio

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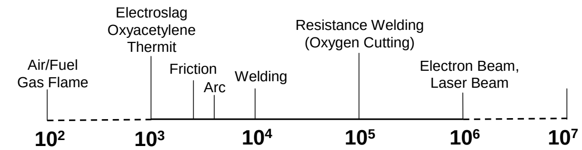
Heat Intensity

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



- Obviously the more intense the source, the faster the melting
- Very difficult to prevent overmelting, therefore automation!

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Heat intensity and interaction time

- Heat intensity (in $^{W}/_{cm^2}$)
  - HI = Power per unit area directed into the welding zone
  - HI ~10^3 melting in < 25 seconds
  - HI ~10^6 vaporizes metal in μseconds
- Propagation of heat in solids: $x \sim (\alpha \cdot t)^{0.5}$
  - x = 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	Tmelt 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

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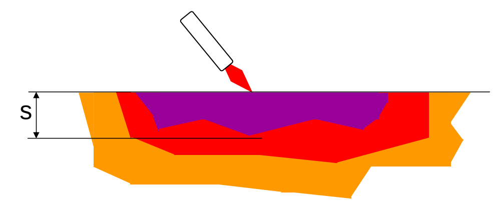
Weld pool from 2D simplification

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

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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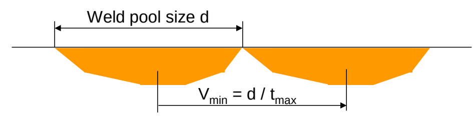
Welding Rate

The rate at which the welding device must be moved is governed by:

- The Heat Intensity - the greater the intensity, the faster the motion must be to keep the weld pool size, s_{max}, constant
- The product, α J_a, The greater it is, the faster the melt front moves

Welding Rate (cont.)

- In fact, the time at a spot, t_{max} is given by $s^2_{max}/ 2\alpha J_a$. Anymore, and you over-melt!



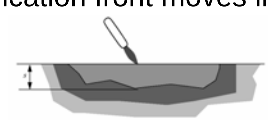
- If the weld pool size is d in length, then you must feed at a rate that exceeds d/t_{max}. Similarly a lower limit.

Melting front and welding velocity

- Definitions of Jacob # and thermal diffusivity:

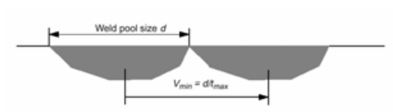
$$J = c_p \cdot \frac{T_{melt} - T_{initial}}{h_{fs}} \qquad \alpha = \frac{k}{\rho \cdot c_p}$$

- 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



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

Welding Rate (cont.)

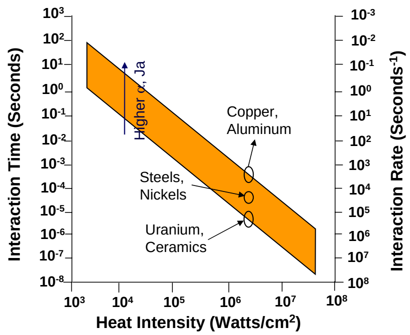
- For a planar heat source on steel,

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

  : where H.I. Is the heat intensity in W/cm^2. The number 5000 includes the material constant related terms.

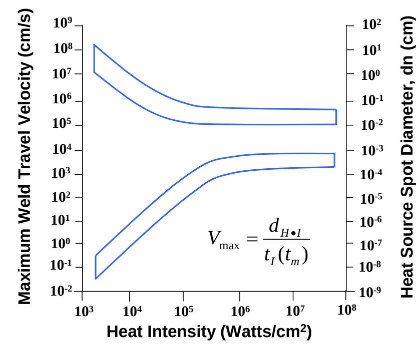
- Clearly the greater the H.I. The faster the metal melts.

Weld Pool – Heat Source Interaction Time



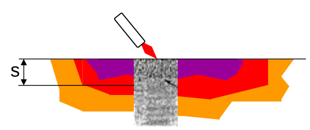
Main factor : Thermal diffusivity

Weld Travel Velocity



Heat Affected Zone

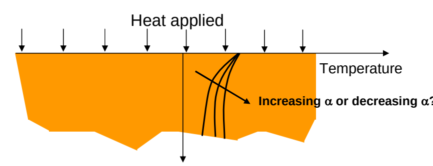
- Region near the weld pool is affected by heat. Microstructure changes.



- The size of the heat affected zone is controlled by the thermal diffusivity, α.

Heat Localization

- Why does alpha affect the size of the HAZ?



- Lower values of alpha, more localized heating, which is better for welding?
- Have you tried taking a soldering iron to plastic? You get small weld pool. But on metal, you heat the whole piece!

FUSION WELDING PROCESSES

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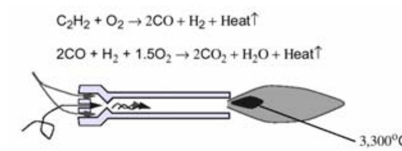
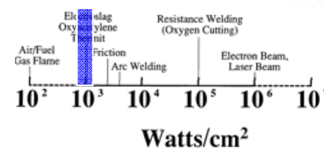
Oxyfuel gas welding

- Air/fuel welding
  - Low-cost, portable and flexible
  - Oxidizing and reducing flames





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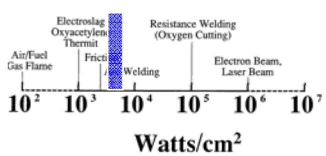
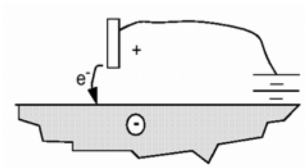
General arc welding

- Voltage difference between electrode & work piece
  - Voltage ~ 100 - 500 V
  - Current ~ 50 – 300 A
- Electrode may be consumed





Arrangement for consumable electrodes

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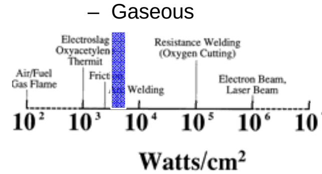
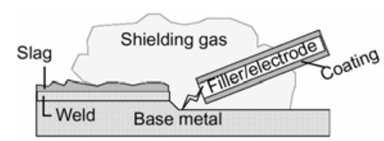
Fillers and shielding in arc welding

- Filler metals
  - Adds metal to weld zone
  - Flux on/in filler cleans/prevents oxidization
  - Slag protects molten puddle from oxidation
- Shielding
  - Pellets or grains
  - Gaseous





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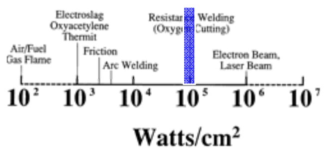
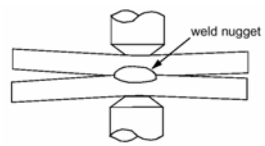
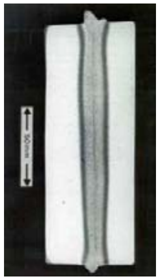
General resistance welding

- High current through weld area (3k – 40k Amps)
  - Important: contact pressure & weld current & weld time
  - Simple, reliable fusion processes
  - Welds often not easy to inspect (i.e. spot welds)
  - Energy in: $i^2 R t$
  - Energy req'd: ?
  - Melting requires ~ 1400 J / g for steel

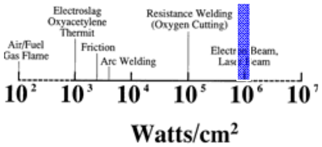




Electron beam and laser welding



- Electron beam
  - Uses electrons to transfer energy
- Laser welding
  - Uses photons to transfer energy
- Pros and cons
  - Advantages: Small HAZ
  - Disadvantages: $$$!, deep welds require careful fixturing



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FUSION WELDING DEFECTS

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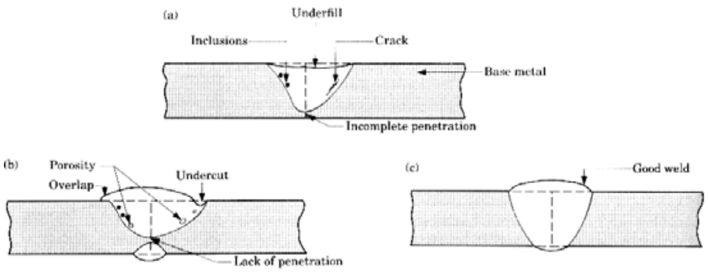
Typical defects



Source: American Welding Society

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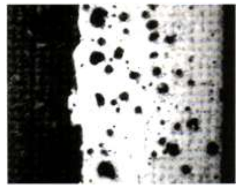
Porosity and inclusions

- Common causes
  - Trapped gases
  - Contaminants
  - Flux particles
- Prevention
  - Pre-heat
  - Pre-cleaning
  - Improved shielding



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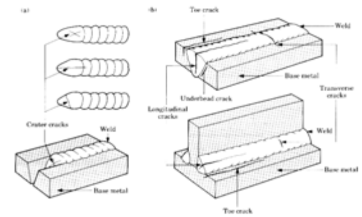
Cracks in welds

- Usually result from one or combo of:
  - Temperature gradients and inability of metal to contract during cooling
- Prevention
  - Preheat components or design to minimize stress from thermal shrinking



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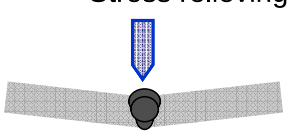
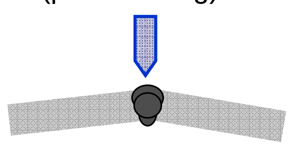
Residual stresses

- Residual stresses cause problems
  - Distortion on welding
  - Reduce fatigue life
- Prevention
  - Preheating
  - Stress relieving in furnace (post heating)



A



B

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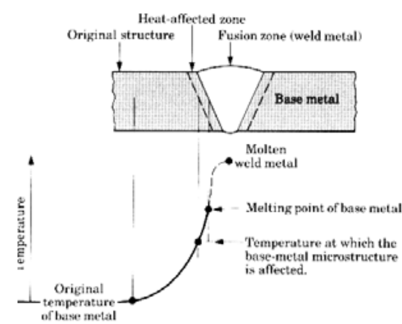
Heat affected zone (HAZ)

- Material is not melted, but is heated
- Properties in HAZ differ and depend on:
  - Temperature
  - Time
  - Original properties
  - HI



FUSION
WELDING
DFM

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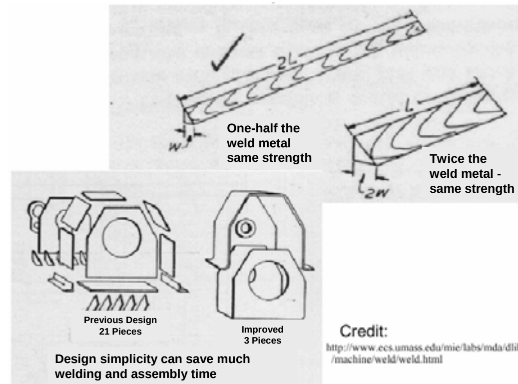
DFM for Welding



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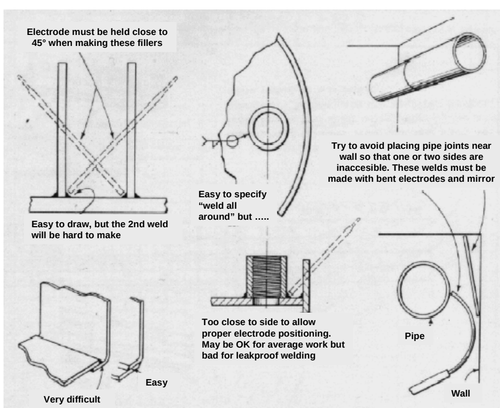
DFM for Welding (conti.)



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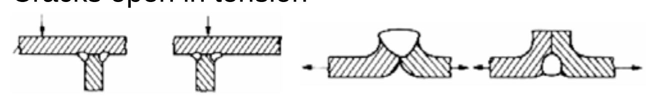
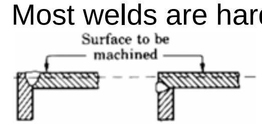
DFM for welding

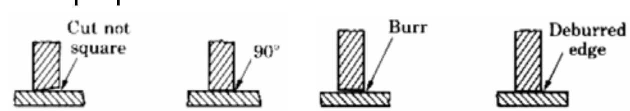
- Cracks open in tension



- Most welds are hard, not easily machined



- Part preparation



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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

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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

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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

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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

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