

# Casting Defects and Design Issues

ver. 1

# Overview

- Processes
- Analysis
- Defects
- Design rules
- Economics

# Issues in Casting

- Shrinkage
- Porosity
- Piping
- Microstructure

# Shrinkage

- Can amount to 5-10% by volume
- Gray cast iron expands upon solidification due to phase changes
- Need to design part and mold to take this amount into consideration

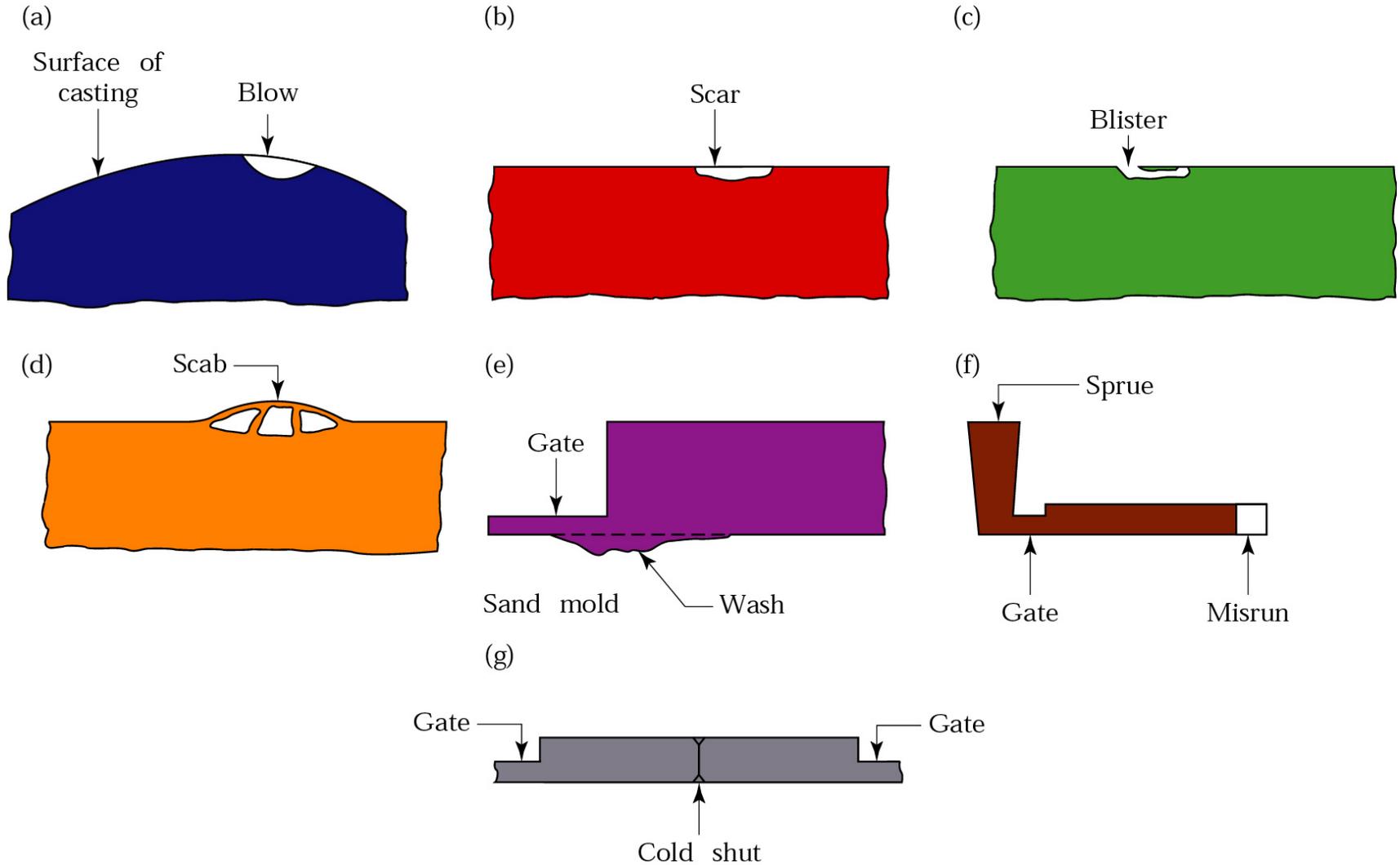
# Shrinkage

TABLE 5.1

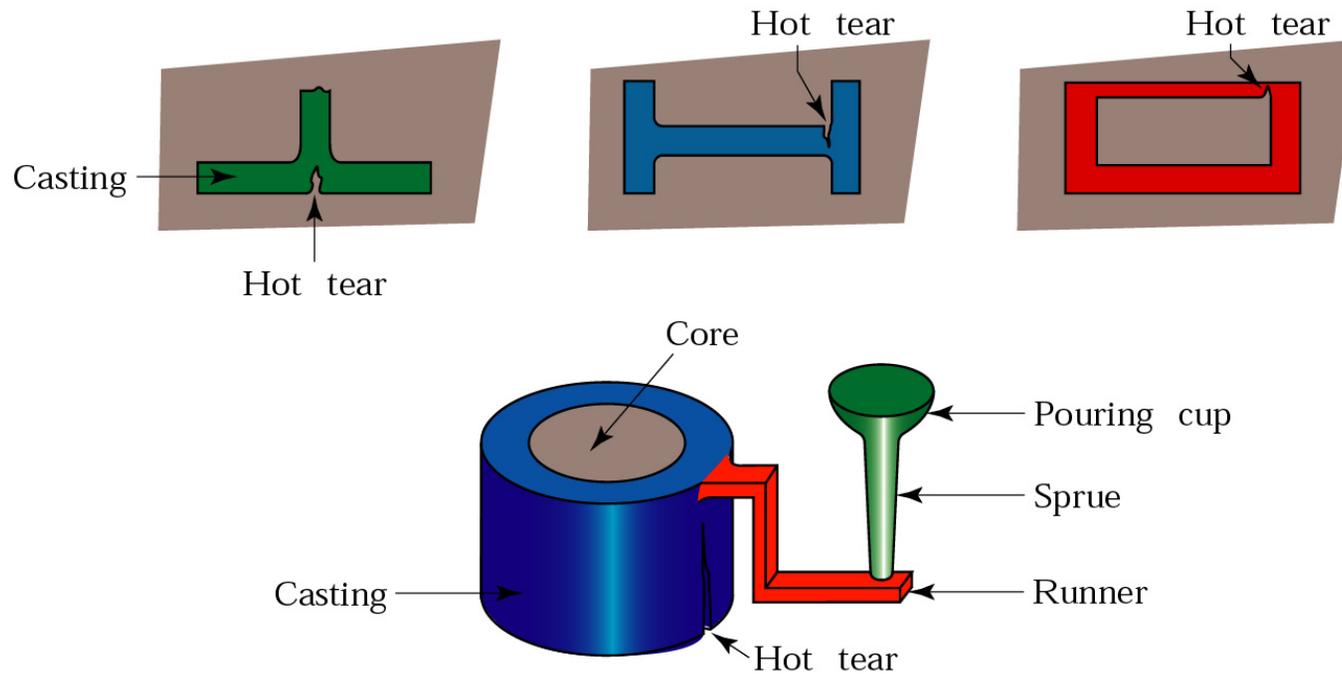
<b>Metal or alloy</b>	<b>Volumetric solidification contraction (%)</b>	<b>Metal or alloy</b>	<b>Volumetric solidification contraction (%)</b>
Aluminum	6.6	70% Cu–30% Zn	4.5
Al–4.5% Cu	6.3	90% Cu–10% Al	4
Al–12% Si	3.8	Gray iron	Expansion to 2.5
Carbon steel	2.5–3	Magnesium	4.2
1% carbon steel	4	White iron	4–5.5
Copper	4.9	Zinc	6.5

*Source:* After R. A. Flinn.

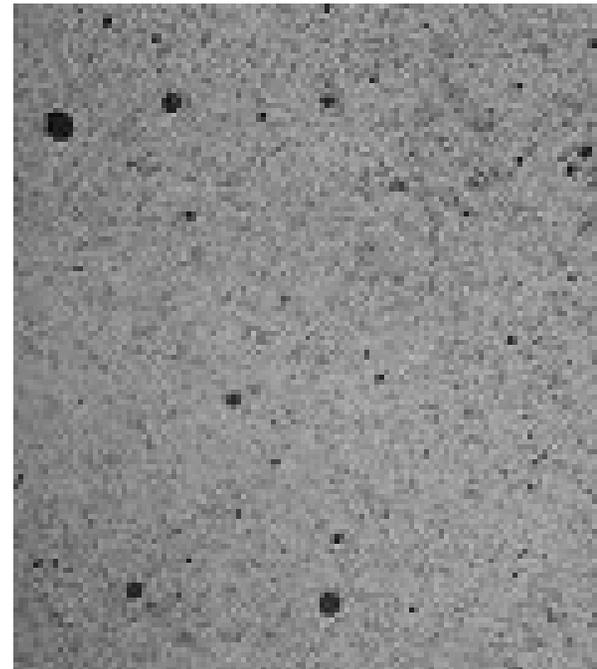
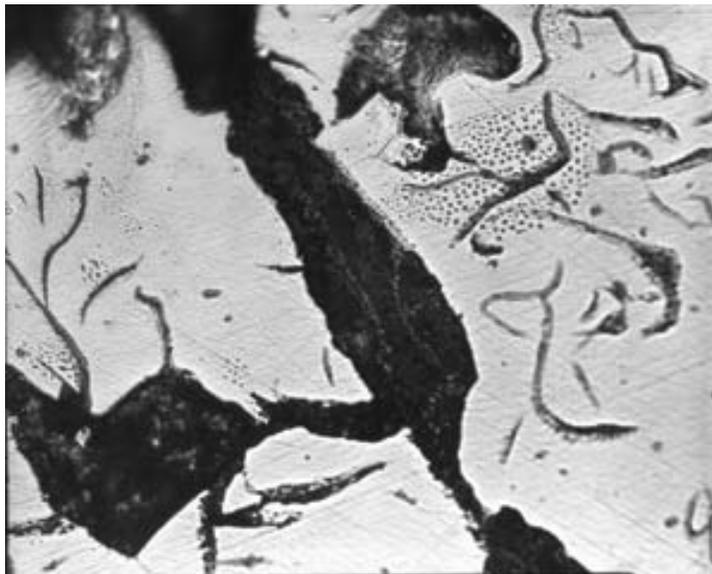
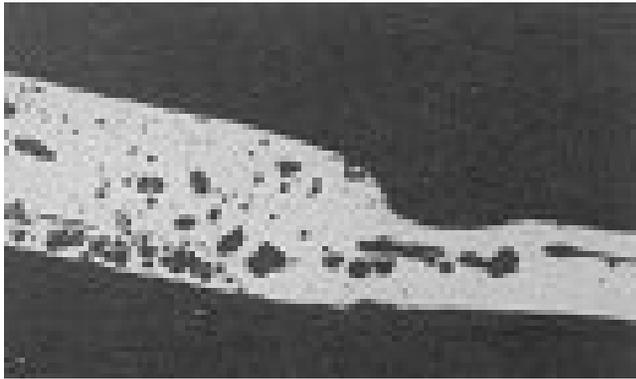
# Casting Defects



# Defects - Hot Tears



# Casting Defects - Porosity



# Porosity

- Types
  - due to gases – smooth bubbles
  - due to shrinkage – rough voids
- Not a problem for ingots
  - parts that will be deformation processed
  - as long as it is not exposed to air (corrosion)
  - can be healed

# Porosity due to Gases

- Smooth bubbles
  - result from entrapped gases
  - solubility in liquid is high, in solid is low, so gas is rejected during cooling

- Sievert's law

$$S = k p_g^{0.5}$$

- $S$  = solubility
- $k$  = constant
- $p_g$  = partial pressure of gas over melt

# Remedies for Gas Bubbles

- Control atmosphere
  - vacuum
  - gases with less solubility
- Proper venting to let gases out
- Proper design of runners and gates to avoid turbulence

# Remedies for Gas Bubbles

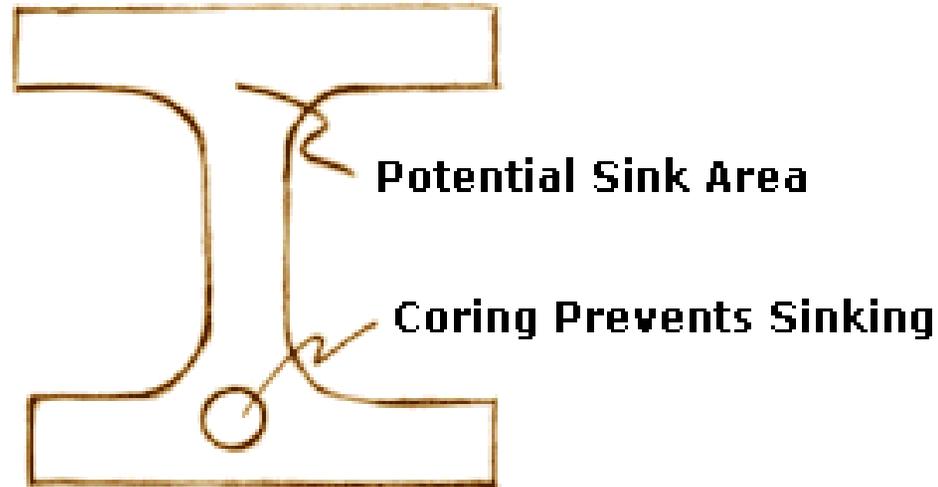
- Add metallic elements to react with gases
  - killed steels - highly deoxidized (Al, Si)
    - high shrinkage due to gas removal - piping
  - semi-killed steels - less deoxidized
    - less piping, porosity
  - rimmed steels - little deoxidization
    - blow holes in ring at rim (sometimes break through)
    - little piping because gas doesn't escape

# Porosity due to Shrinkage

- Rough bubbles - voids
- Stages
  - cooling liquid
  - rejects latent heat at melting point
    - alloys become slushy - liquid and solid co-exist
  - cooling solid

# Differential Cooling

- Transition between thicker and thinner sections can lead to porosity



# Porosity / Shrinkage Solutions

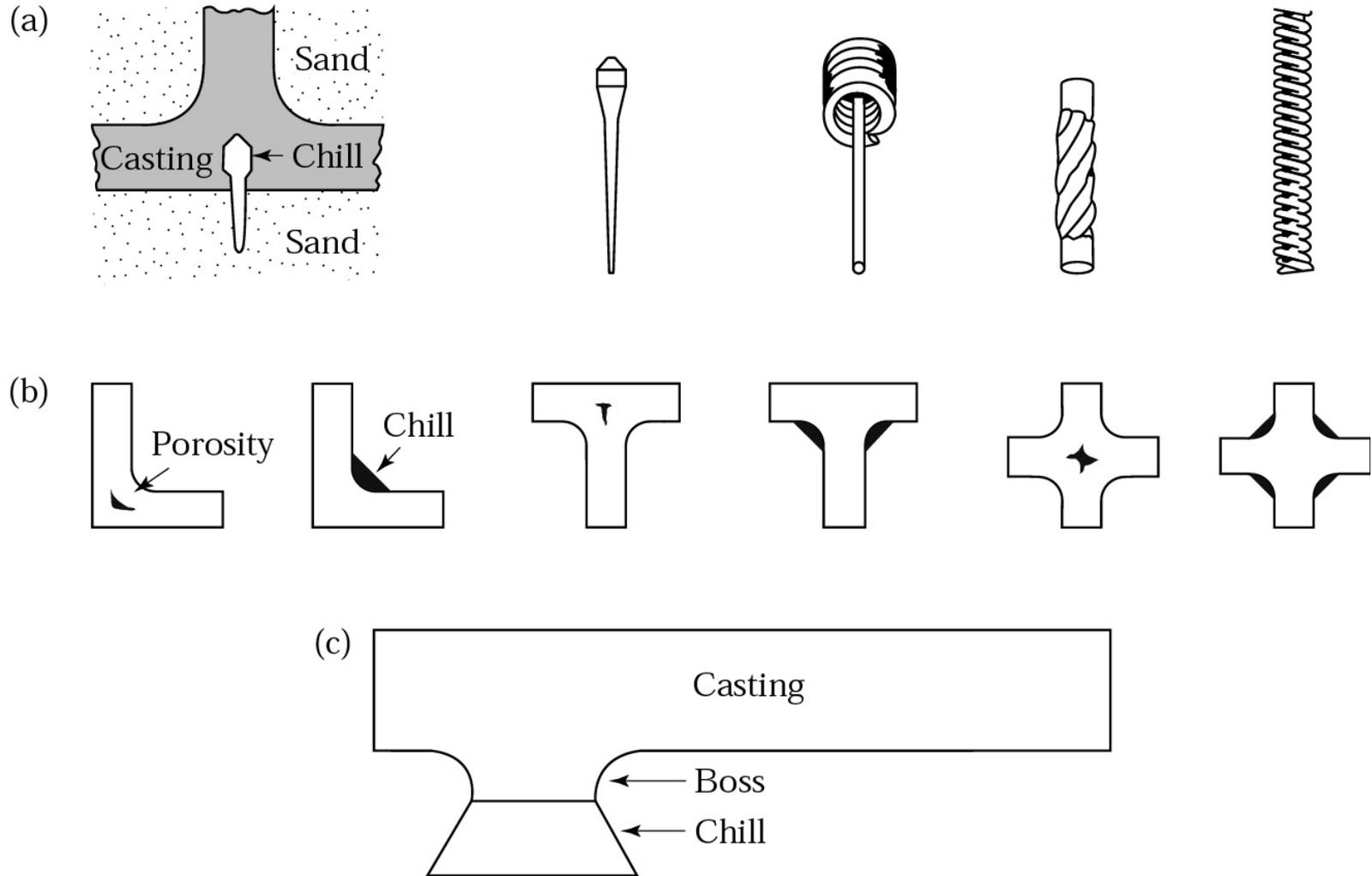
- Risers allow molten metal to flow into mold to make up for shrinkage
- Design flow so no part freezes early
  - large channels
- “Flexible” molds
  - allow metal to shrink, not hold metal

# Porosity / Shrinkage Solutions

- Heating or cooling certain areas to maintain uniform cooling (thermit or chills)
- Uniform part thickness
  - leads to uniform cooling, less residual stress

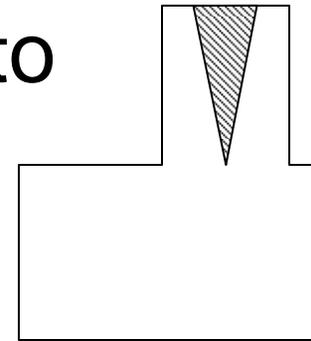


# Chills

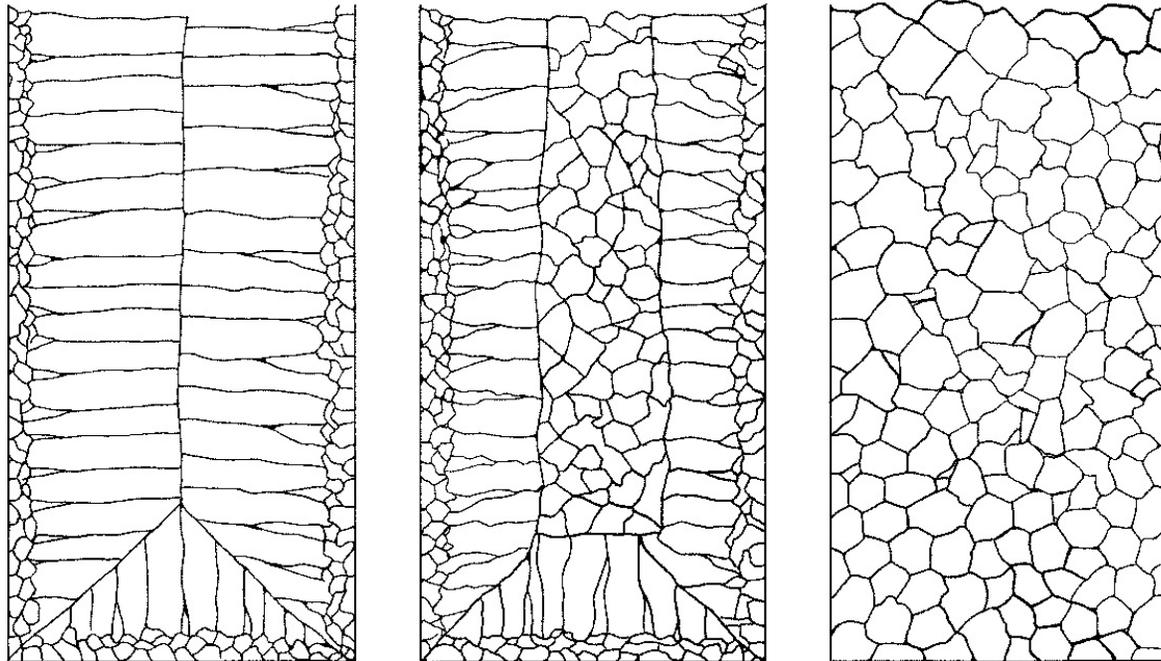
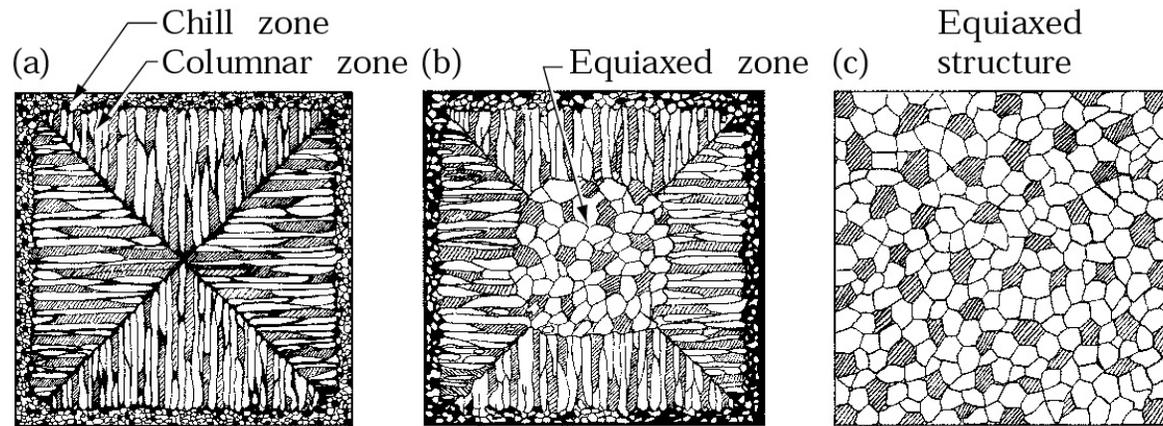


# Pipe Defect

- Due to shrinkage giving rise to a funnel-like cavity
- Solutions
  - insulate top (glass wool)
  - heat top (exothermic mixture - thermit)



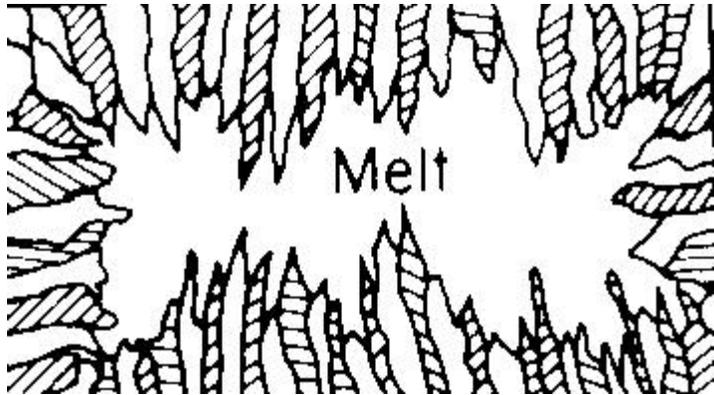
# Microstructure



# Grains on Willie B's head

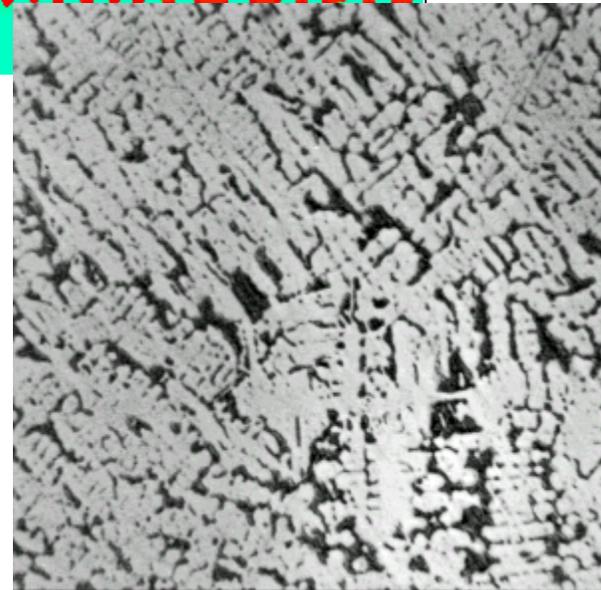
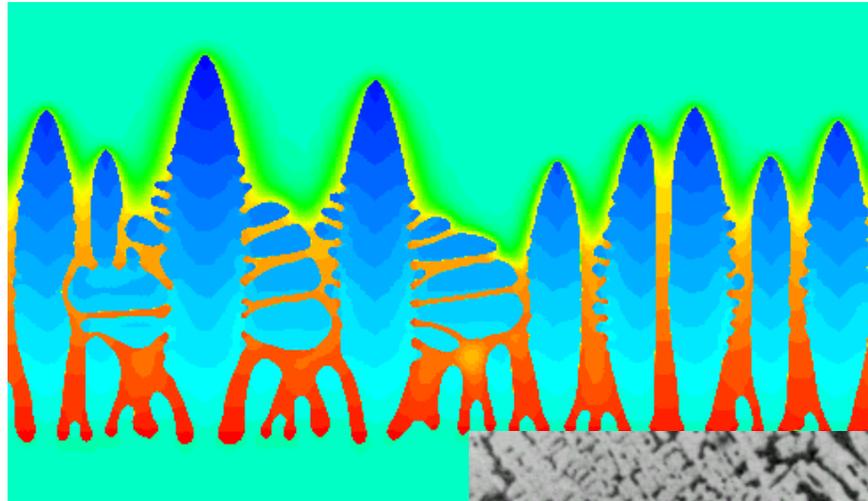
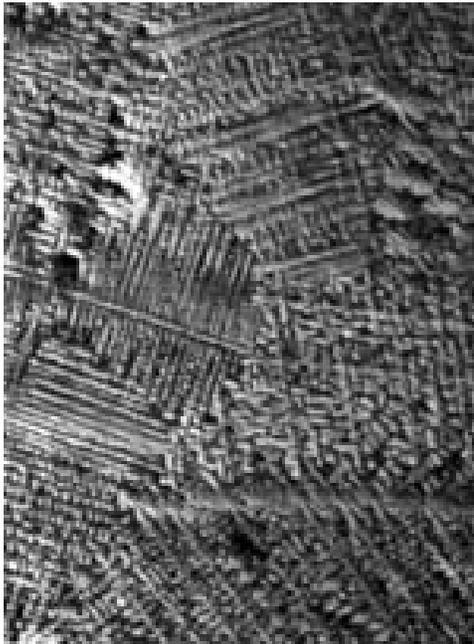


# Microstructure - Dendrites



- Finer structure at walls
- Grains / dendrites grow to center

# Microstructure - Dendrites

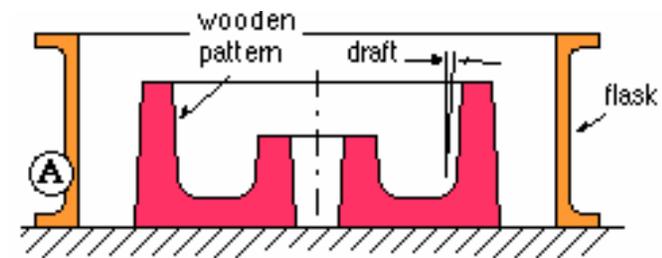


# Microstructure

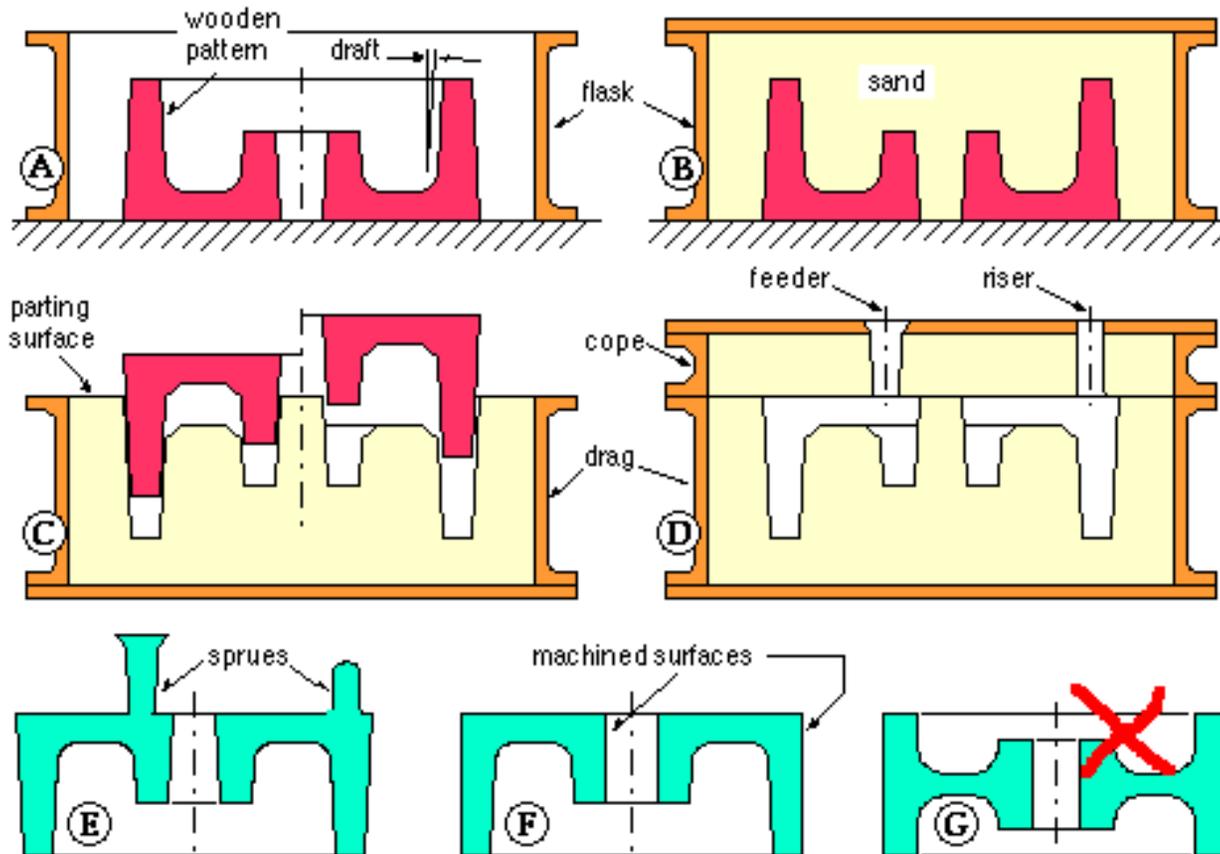
- Post-treatment may be necessary to get desired properties - grain structure
  - annealing
  - tempering
  - cold working

# Design Rules Summary

- Uniform wall thickness
- Flat parting lines
- Gradual thickness transitions
- Draft for removal
  - tapers: 0.5 to 2 degrees
- Surface of mold gives surface of part



# Sand Casting Rules



# Economics Example - Optical Bench



# Requirements

- Casting of Al-Si alloy
- Number
  - one-off
  - preliminary run (100)
  - production run (10,000)
- High precision required
  - machining required
  - pick cheapest casting method

# Alternative Processes

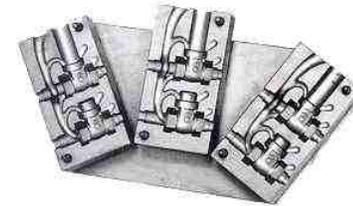
- Sand casting



- Low pressure casting



- Permanent mold casting



- Die casting



# Cost Equation

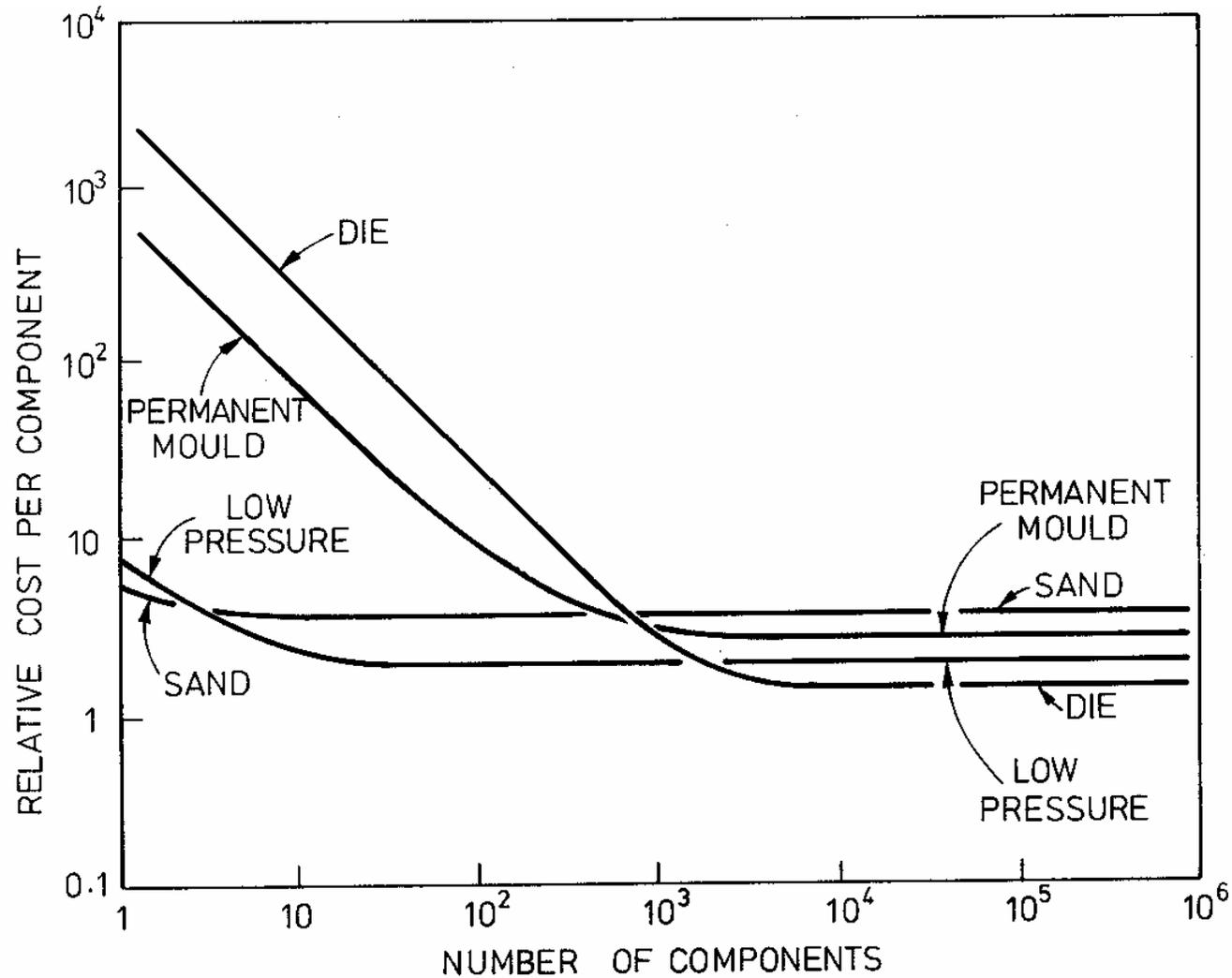
$$C = C_m + \frac{C_c}{n} + \frac{C_L}{\dot{n}}$$

- $C$  = cost/part
- $C_m$  = material cost
- $C_c$  = capital cost
- $C_L$  = labor cost
- $n$  = number produced
- $\dot{n}$  = production rate

# Process Costs

Process	Sand Casting	Low Pressure	Permanent Mold	Die Casting
Material, $C_m$ (\$)	1	1	1	1
Labor, $C_L$ (\$/hr)	20	20	20	20
Capital, $C_C$ (\$)	0.9	4.4	700	3000
Rate, $\dot{n}$ (#/hr)	6.25	22	10	50

# Process Economics



# Process Selection

- Probably pick low pressure casting, as a preliminary run of 100 is assured.
- If production run is needed, die casting will probably be used.
- The tough part is getting the process cost data.

# Production of Aluminum Auto Parts

Main Characteristic	Casting Gravity <sup>A</sup>	Low-Pressure Die Casting <sup>B</sup>	High-Pressure Die Casting (Pores Free) <sup>C</sup>	Squeeze Casting <sup>D</sup>
Pouring/Filling Method	Ladle	Air pressure through stalk	High-speed and high-pressure injection by hydraulic piston	Relatively low-speed and high-pressure injection
Filling Time (s)	10-30	10-30	1	10
Operating Pressure (atm.)	1	1+(0.2-0.5)	100-500	500-1,000
Cycle Time (min.)	5-10	5-10	1-2	2
Die/Mold Temperature	High	High	Low	Low-medium
Dimensional Accuracy	+	++	+++	+++
Design Availability	+++	++	+	+
Productivity	+	++	+++	+++
Quality	+	++	+ - +++	+++
Cost	+	+	+++	+++
Machining Required	Many	Many	Few	Few
Main Parts (other than wheels)	Intake manifold, cylinder block and head, piston	Cylinder block, cylinder head, suspension, member	Cylinder block, oil pan, cylinder head cover, transaxle case	Piston, disk-brake caliper, power steering toe control hub, knuckle

# Advantages of Casting

- Near- or net- shape
- Less scrap
- Intricate shapes
- Large hollow shapes
- No limit to size

# Disadvantages of Casting

- Shrinkage, porosity, cracks
- No strain hardening
  - can be brittle
- Tooling can be expensive
  - part shape depends on tool (mold)
- Microstructure can be difficult to control
  - non-uniform cooling
  - faster on outside produces finer grain structure there

# Summary

- Defects
- Design rules
- Economics

