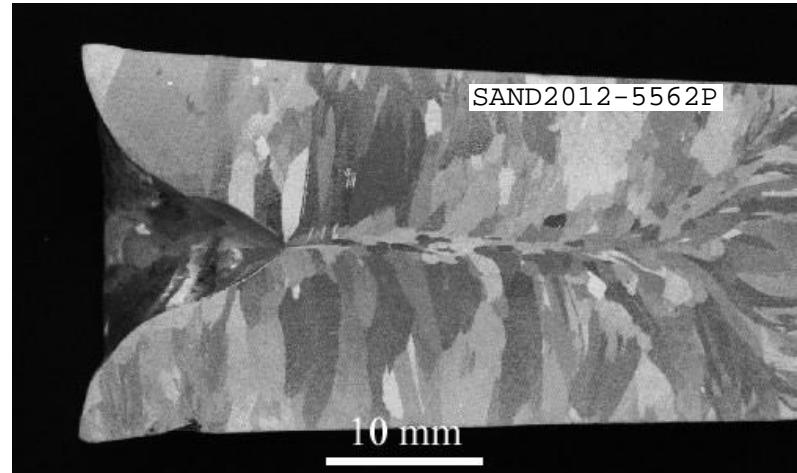


Lippold, Welding Metallurgy & Weldability of Stainless Steels, Wiley, 2005

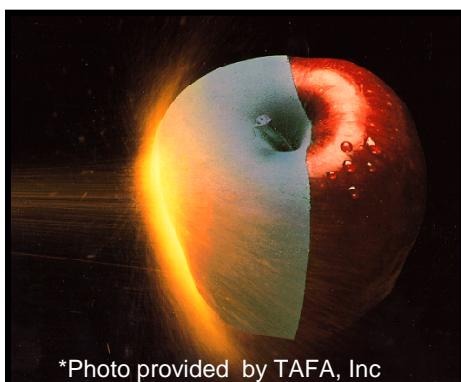


[http://www.doitpoms.ac.uk/miclib/full\\_record.php?id=615](http://www.doitpoms.ac.uk/miclib/full_record.php?id=615)

# Introduction to Metals

## ASM Teachers Camp

### July 9, 2012



\*Photo provided by TAFA, Inc

Deidre A. Hirschfeld

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[dhirsch@sandia.gov](mailto:dhirsch@sandia.gov)

\*Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.



# A Challenge!

## Be a Mr. Lauff!

Encourage students to think “outside the box:”

- ◆ **Careers – Pursue Your Dreams!**
- ◆ **Opportunities – Summer Programs, Competitions, Science Fair, MESA, Science Olympiad, & More**



# The Basics

## Materials Scientists & Engineers Make and Improve Stuff We Use!

Scientists and Engineers Are Always  
Discovering New Concepts But How Do  
These Concepts Become Reality?

- All New Technological Developments Rely  
on Materials
- Famous Quote: Scientists Discover New  
Worlds But Engineers Create Them.



# The Basics

- The Transistor Became a Commercial Success in the 1950's Because of a Metallurgist.
  - At Bell Labs, physicists walked down the hall and talked with Bill Pfann about how to practically make doped silicon. Bill developed Zone Refining and the rest is history.
- The Rapid Improvement in Computer Technology Is Due to Advances in Materials
  - More Data Can Be Stored In A Smaller Space
  - Techniques for Making Circuits/Chips Have Become More Accurate on a Smaller Scale
  - What is next? Optical, Biological, ... ?



# The Basics

## Discipline of Materials Science & Engineering

Utilize Both Physics and Chemistry Principles  
to Understand and Advance Knowledge of  
Solid Materials

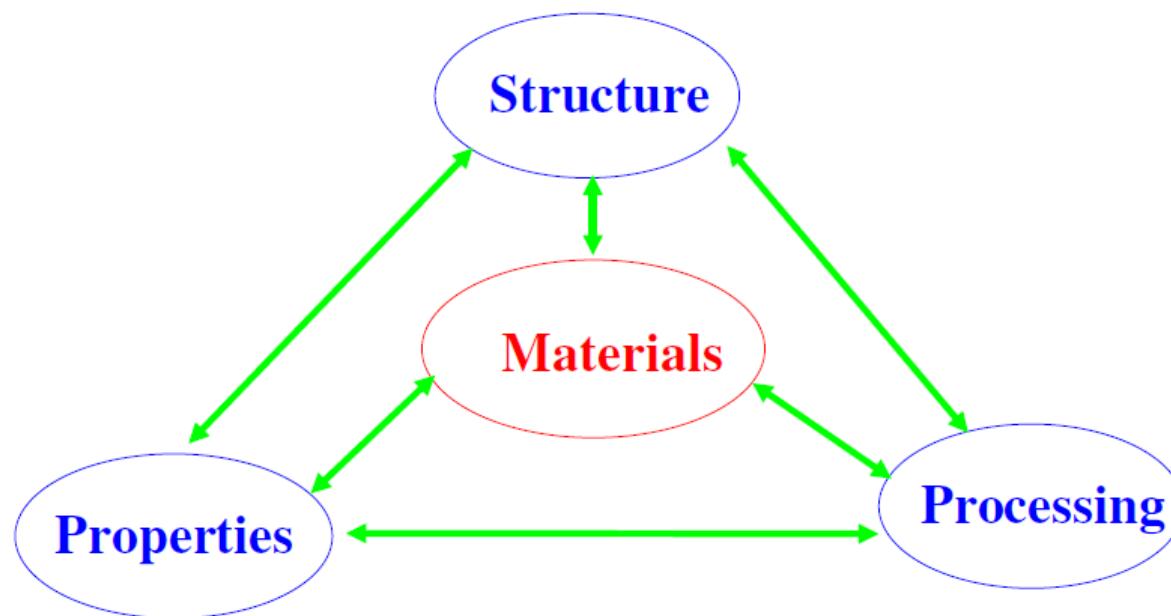
Traditional Areas: Metals, Polymers,  
Ceramics, Composites

New Areas: Biomaterials, Nanomaterials



# The Basics

Materials Scientists & Engineers Study the Relationship Between Structure, Properties, and Processing of Materials





# Metal Statistics

## Some Interesting 2008 Statistics:

- Over 1.4 Billion Tons of ALL metals produced in the world more than double 1970 production, 7x 1950's
- Steel accounts for 95% of total followed by Al (~40M Tons), Cu, Zn
- US per capita metal usage 380Kg
- Extraction Waste Materials (excluding overburden) ~4X weight of metals produced
- About 35% of Steel is produced from Scrap Saving 45-75% of energy over Steel produced from Iron Ore
- Aluminum from Scrap vs. Bauxite uses only 5-10% as much energy
- Aluminum smelting from Bauxite used 50K kWh per ton in 1900, 25K in 1950, and 16K in 2000

<http://www.commodities-now.com/news/metals-and-mining/612-world-metal-production-surges.html>



# Metal Statistics

## 2010 Production of Steel

Country	Production (Metric Tons)
European Union	172.7
CIS (Former Soviet Union)	108.2
NAFTA	111.4
South America	43.9
Africa	16.6
Middle East	20.6
China	672.0
Japan	109.6
Other Asia	166.3
Oceania	8.3
Other Europe	33.6
Total	1463

<http://www.commodities-now.com/news/metals-and-mining/6994-global-steel-output-to-reach-157-bn-tons-2011.html>



# History of Metals

- Process Metallurgy is one of the oldest applied sciences!
  - Gold discovered ~ 6000 BCE
  - Copper ~4200 BCE
  - Silver ~4000 BCE
  - Lead ~ 3500 BCE
  - Tin ~1750 BCE
  - Iron Smelted ~1500 BCE, “Crude” Steel 1000 AD
  - Mercury ~ 750 BCE
- Gold, Silver, Copper, Iron, and Mercury were found in their native state
- 13<sup>th</sup>-14<sup>th</sup> Centuries – Arsenic, Antimony, Zinc, and Bismuth
- 16<sup>th</sup> Century – Platinum
- 1700's – Cobalt, Nickel, Manganese, Molybdenum, Tungsten, Tellurium, Beryllium, Chromium, uranium, Zirconium and Yttrium
- The 1800's yielded over 40 new metals and 19 in the 20<sup>th</sup> Century



# Deconstruction of a Can

## A Soda Can: Where, How, What, and Why



\*Courtesy of Novelis Corporation



# Extractive Metallurgy

From the earth/chemicals to finished product vs. Recycling

- Pyrometallurgy – Metals Made Using Heat
- Hydrometallurgy – Metals Made Using Water and Chemicals
- Biological Extraction – Utilizes Bacteria



<http://www.art-wallpaper.com/2582/Bruegel+Pieter/The+alchemist-1024x768-2582.jpg>



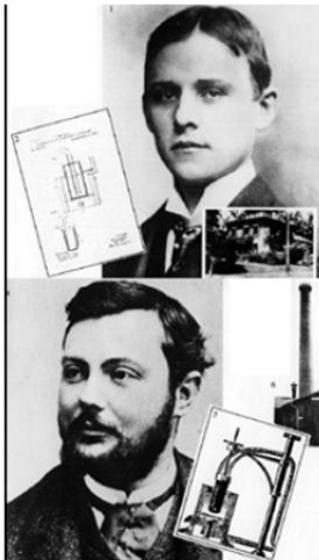
# Extractive Metallurgy

## Mining, Communion, Benefication





# Aluminum Processing



Bayer Process converts Bauxite to Alumina which is converted to Aluminum using the Hall Heroult Process

Al first extracted in early 1800's but very difficult

In late 1880's, Hall and Heroult simultaneously discovered a process to reduce alumina to aluminum metal. As the technology developed, the metal became affordable.

[http://doc.tms.org/ezMerchant/graphics.nsf/Images/HHCentennial/\\$FILE/HHCentennial.gif](http://doc.tms.org/ezMerchant/graphics.nsf/Images/HHCentennial/$FILE/HHCentennial.gif)

# Aluminum Processing

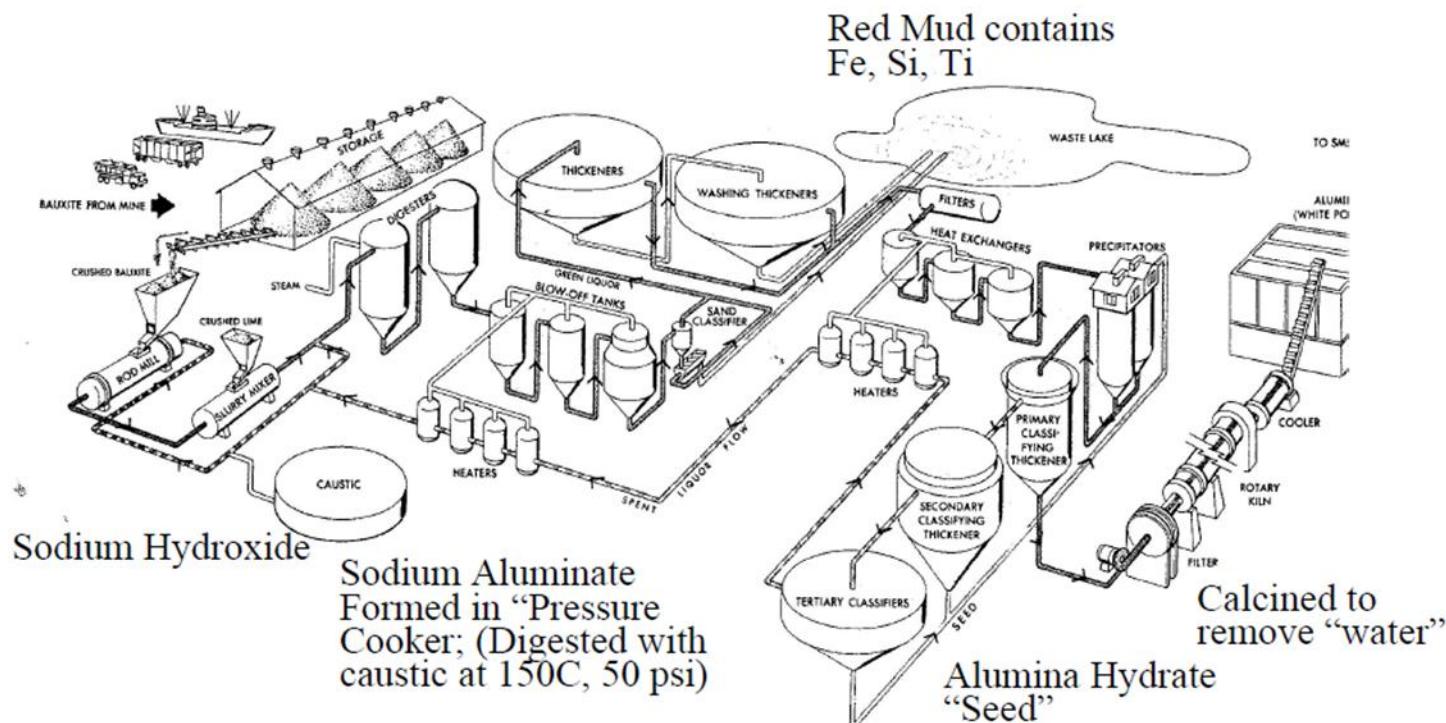
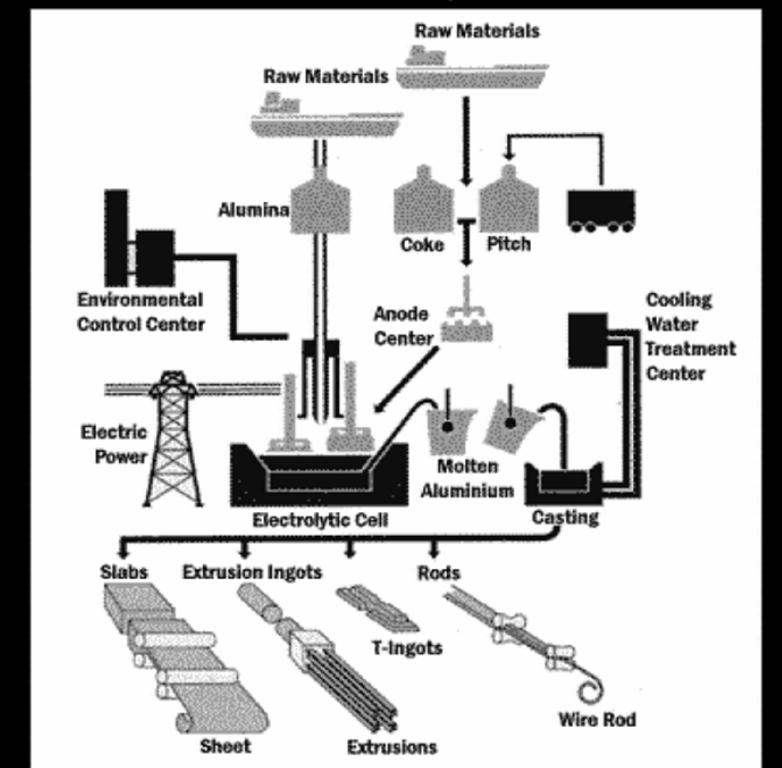


Fig. 3.4 The Bayer process for chemically refining bauxite into alumina. (Courtesy of Alcoa Inc., Pittsburgh, PA.)

## Production of Primary Aluminum

Source: IPAL, 1993



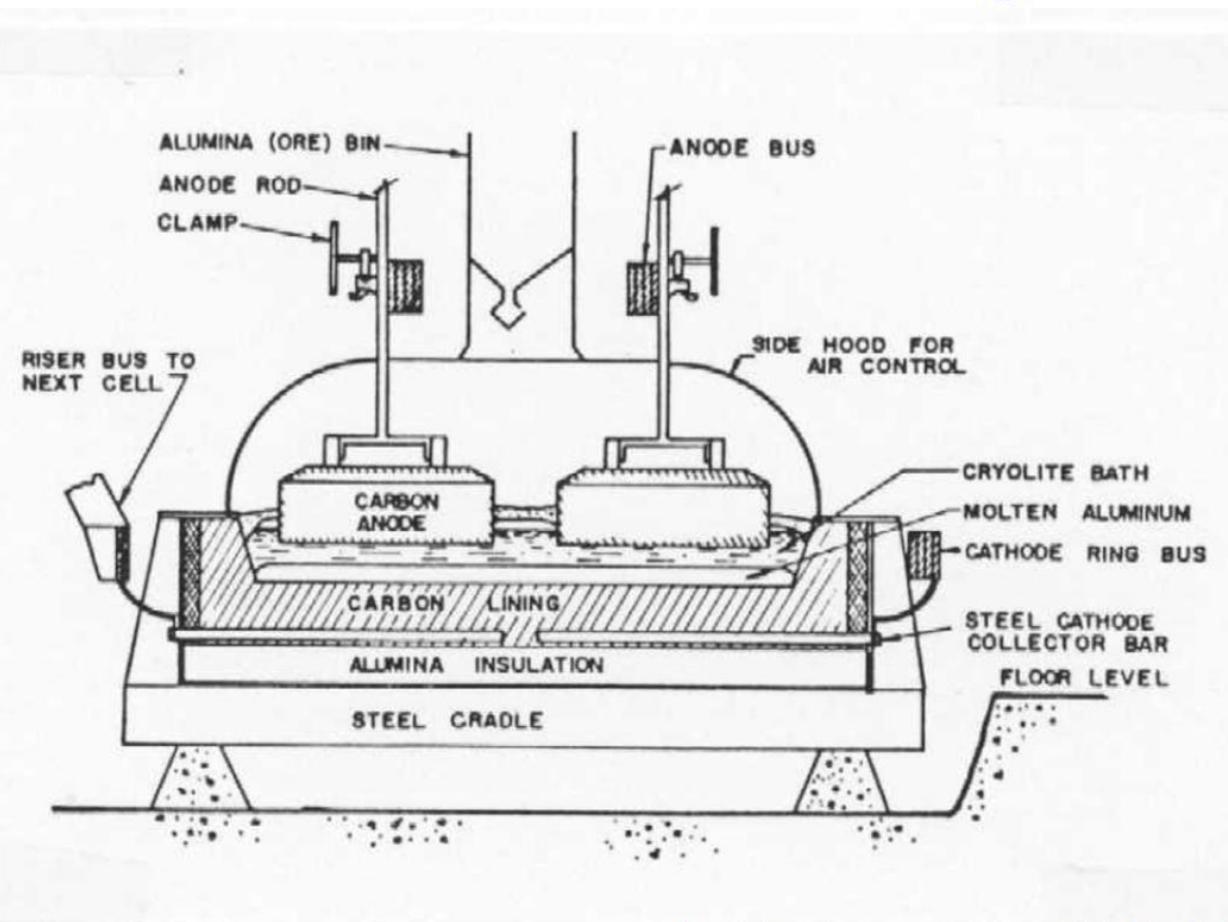
## Aluminum Processing

Only ~5% of Power Required to Recycle vs. Smelt!

<http://www.epa.gov/highgwp/aluminum-pfc/images/exhibit2.gif>



# Aluminum Processing



<http://electrochem.cwru.edu/ed/encycl/fig/a01/a01-f02b.jpg>

# Forming: Rolling

Hot Working:  $0.6T_m$

Cold Working:  $RT-200C$

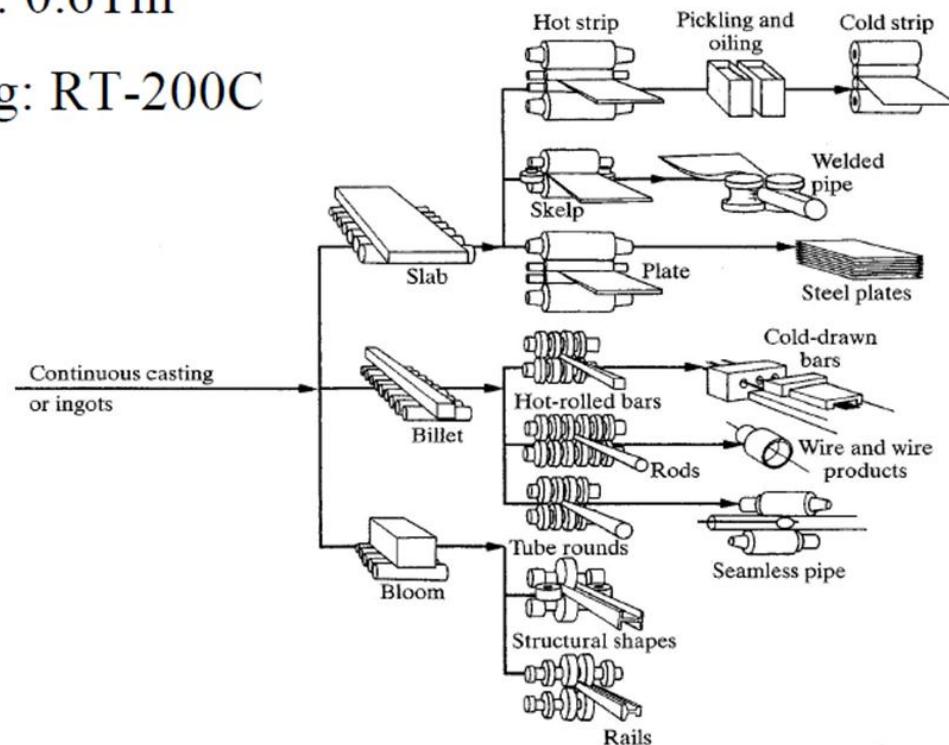
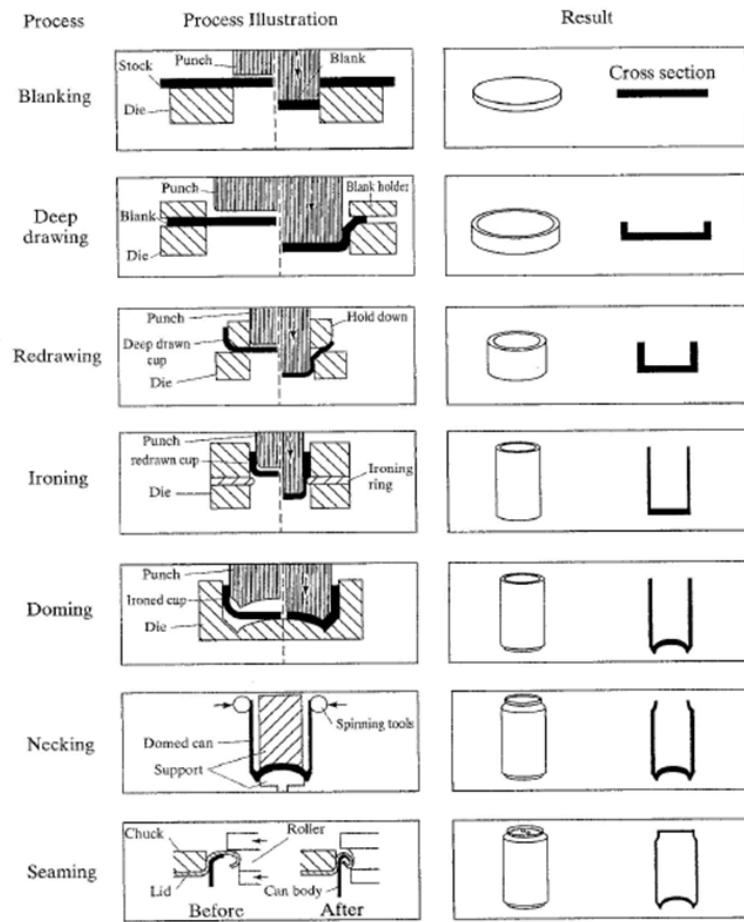


FIGURE 13.1 Schematic outline of various flat- and shape-rolling processes.  
Source: American Iron and Steel Institute.

FIGURE 16.31 The metal-forming processes involved in manufacturing a two-piece aluminum beverage can.



## Al Can Production



<http://www.constellium.com/markets/packaging/food-and-beverage/can-body-stock>

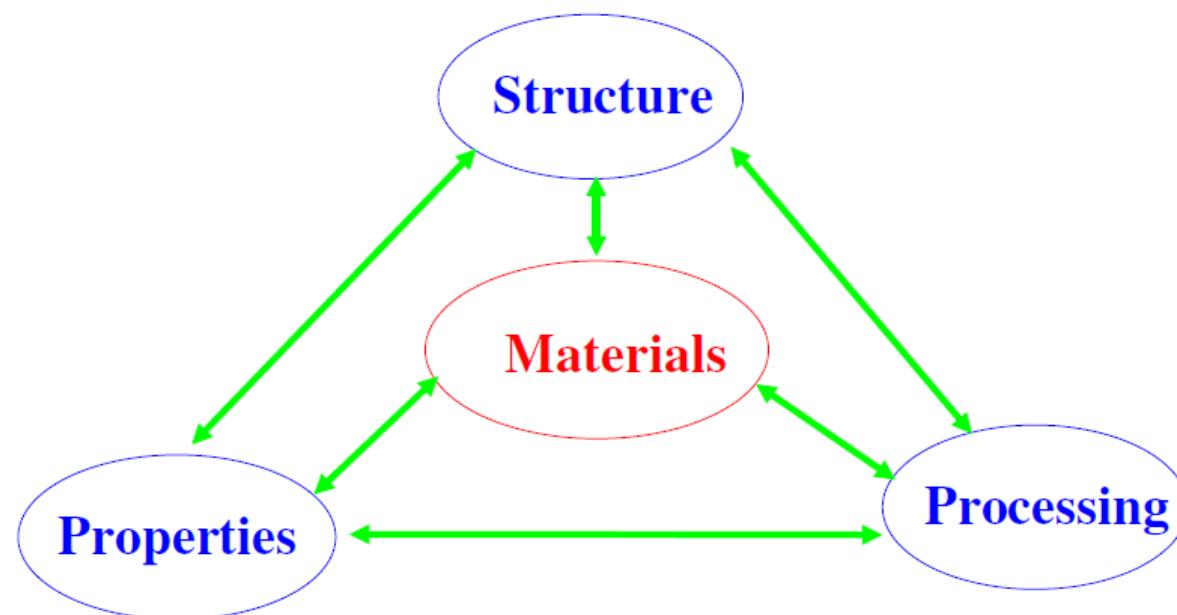
Source: Kalpakjian, Manufacturing Processes for Engineering Materials



# Back to The Basics

**Why do we make cans this way?**

Because of the Structure and Properties of Aluminum



## The Structure of Materials Is Examined in Terms of Scale

There Are Three Broad Size Ranges That Can Be Further Divided into Important Subsets

- **Atomic** Scale How Individual Atoms Are Assembled and Bonded Together
- Cluster Scale Clusters of Atoms from Nanometers to Micrometers (**Nano, Meso, Micro**)
- **Macro** Scale From Millimeters to Skyscrapers

## Atomic Bonding Is Critical!

Why is Bonding Important?  
Materials Properties and Processing Depend  
on Atomic Bonding

Four Types of Bonds:  
Covalent, Ionic, Metallic, and Weak

## Metallic Bonding

- Atoms Have Electron Clouds Around Them Which Are Shared with Other Atoms
  - Copper: Electrons Can Easily Move from Atom to Atom Allowing Electrical Conductivity and Deformation
- Not Very Strong Bonds as compared to Covalent or Ionic

## Properties of Materials Depend on Bonding

- Melting Point or Softening Point
- Electrical and Thermal Conductivity
- Mechanical Properties (Strength, Toughness)
- Etc.

## How Do Atoms Join Together?

- Crystalline – Ordered Structure
  - Imagine Balls Stacked in Ordered Arrays
  - 14 Basic Forms of Packing Balls Together in an Ordered Manner
- Amorphous No Long Range Order
  - Imagine a Bowl Full of Spaghetti, Water Soaked Beans Swelled in a Jar, or A Crystalline Structure that is ordered for very short distances.

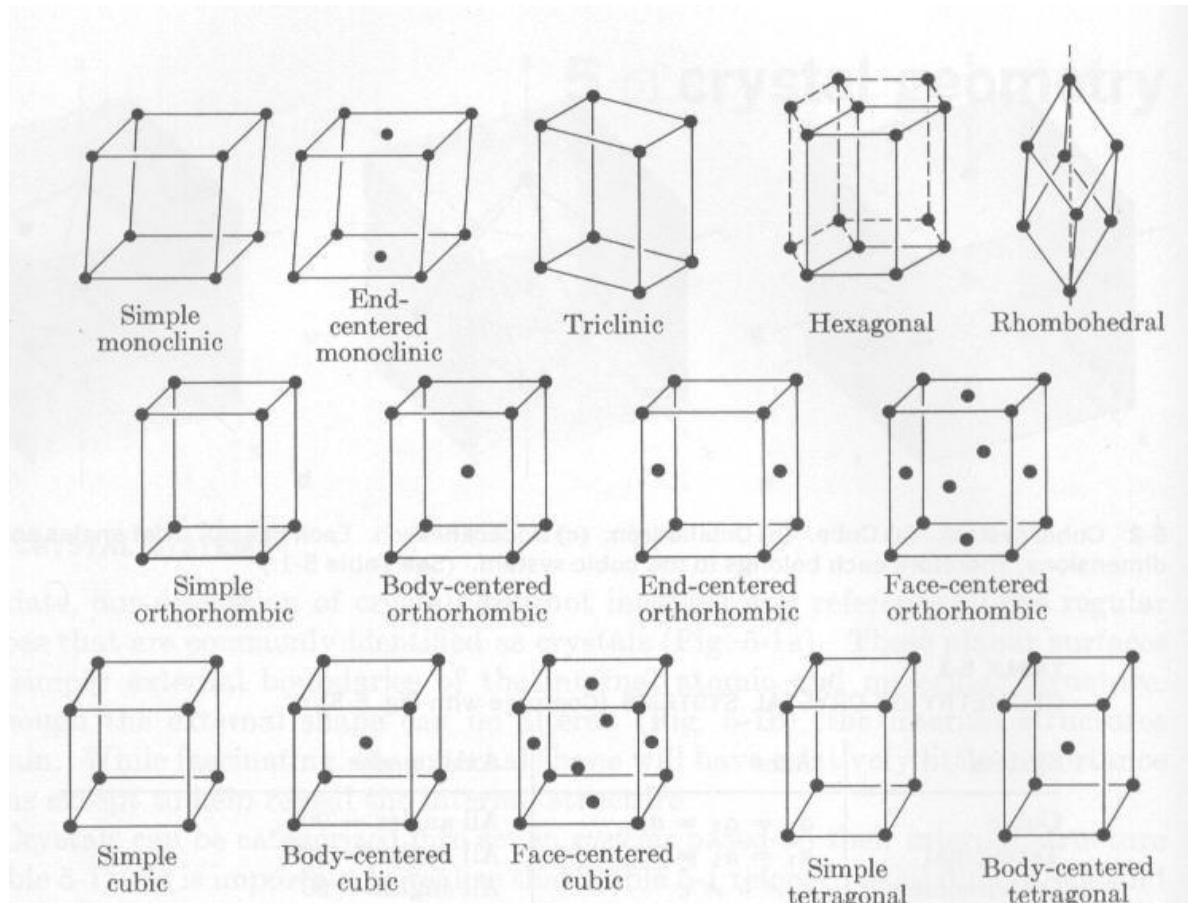
## Crystal Structures

There are 14 Basic Ways to Pack Atoms Together!

Mechanical and other Properties of Metals and Ceramics Depend on the Crystal Structure

# Structure

## 14 Bravais Crystal Structures

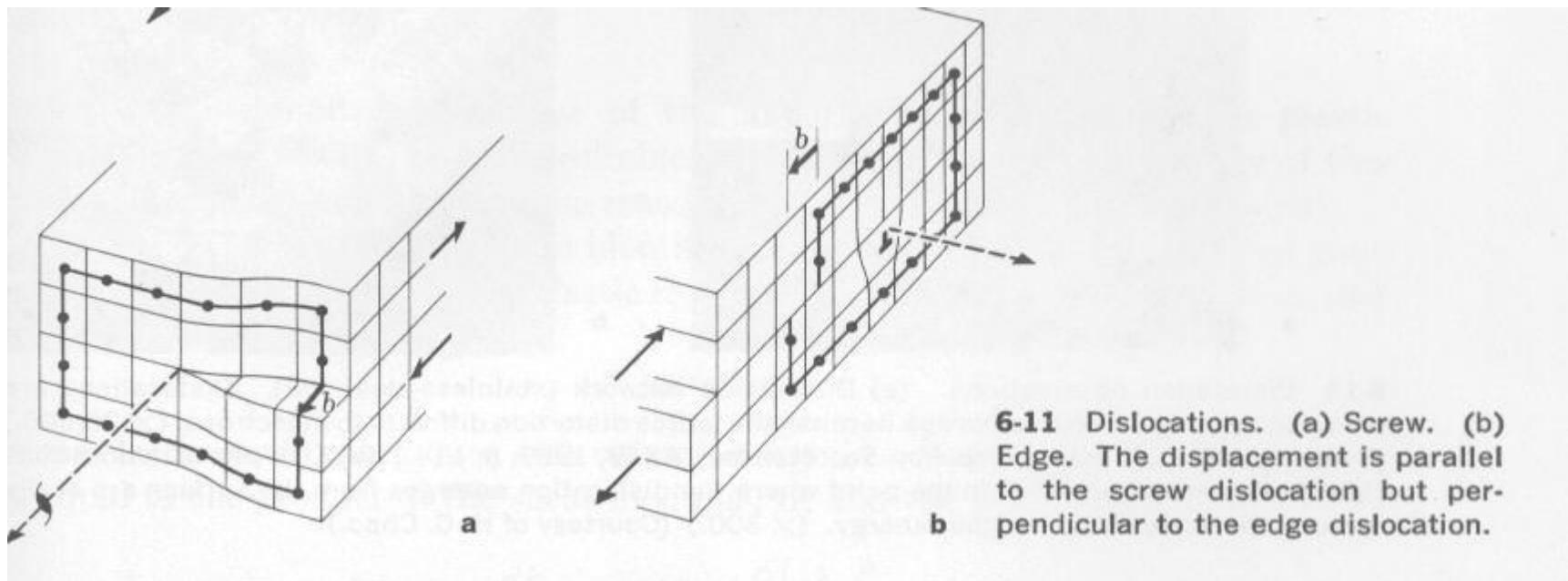


## How Does Crystal Structure Affect Mechanical Properties?

Dislocations and Slip Systems Determine Properties: Stiffness, Strength, Elongation

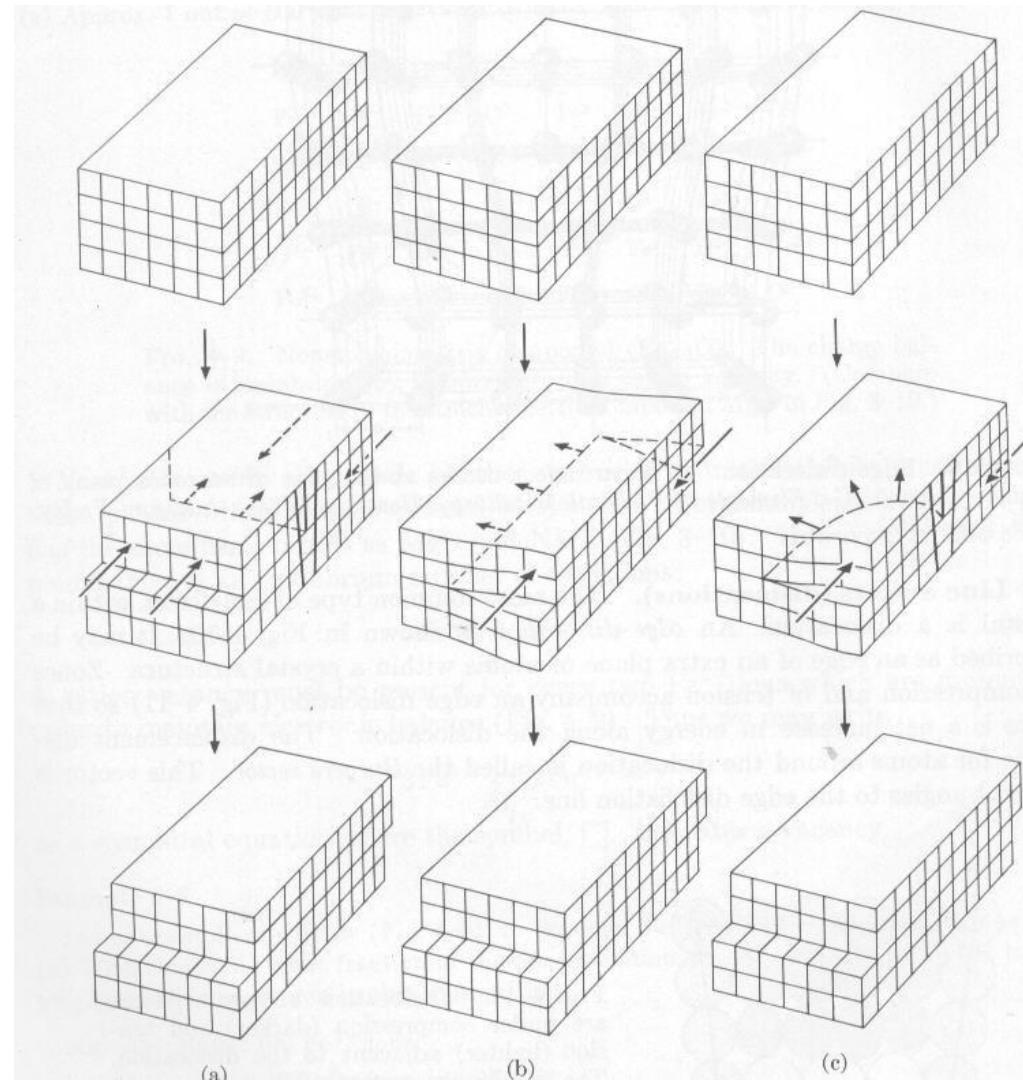
(How Atoms Move in the Crystal Lattice Subject to an Applied Load)

## Dislocations – Extra Planes of Atoms in a Crystal Structure





# Structure: Dislocations



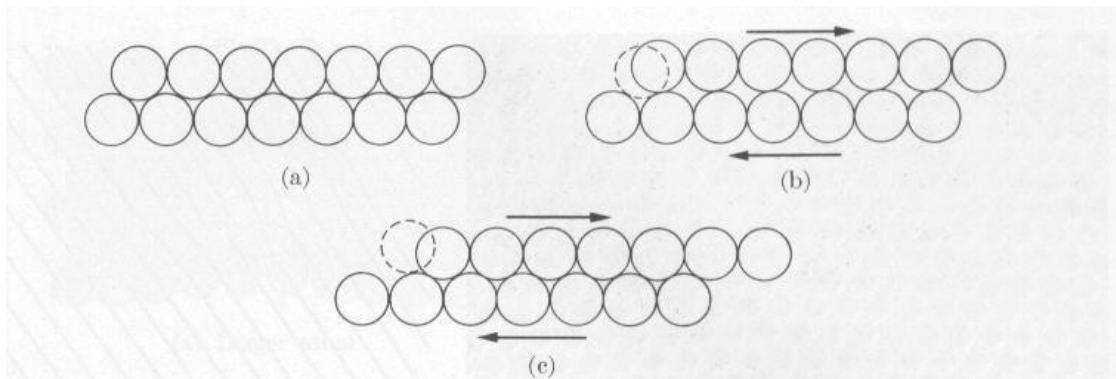
## Slip Systems

Planes and Directions in Lattice Where Atoms Can Move Easily

Where Atoms Are More Closely Packed Together, the Atoms Slide Across Each Other More Easily.

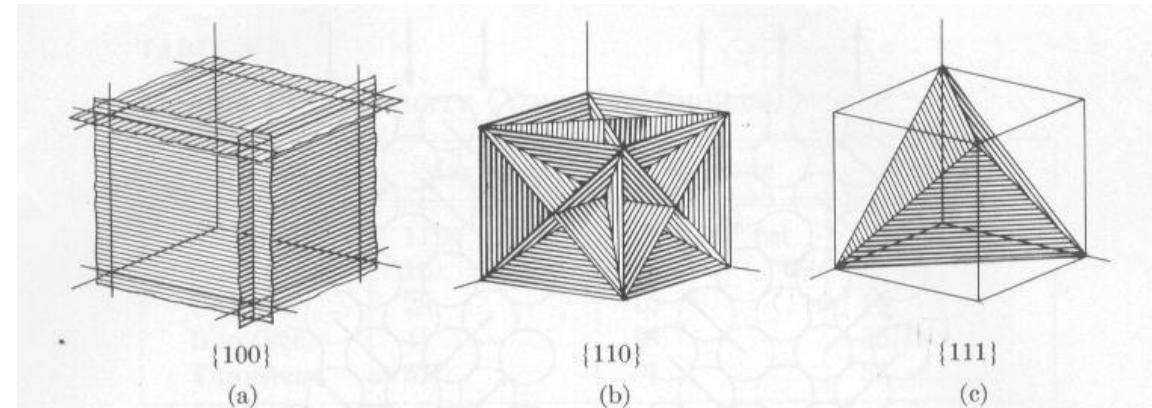


# Structure: Dislocations



How Much Energy Is Required to Move Planes of Atoms?

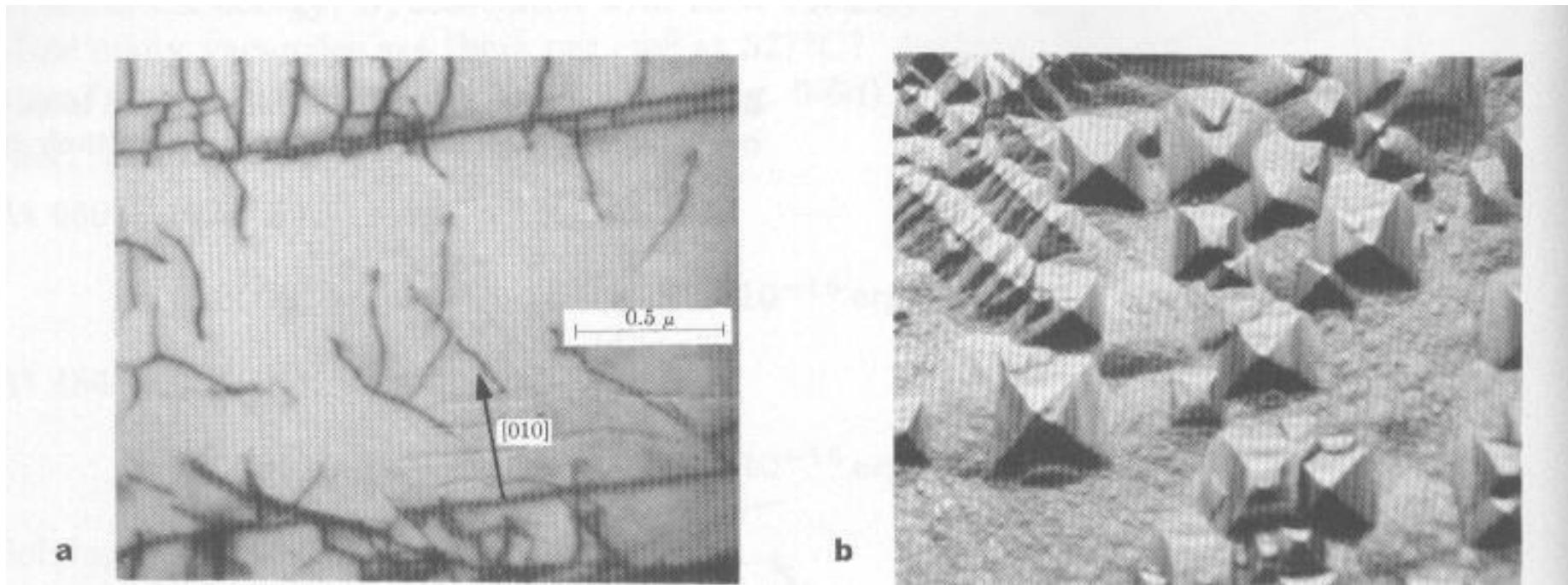
Slip Systems allow easy movement!





# Structure: Dislocations

## Real Dislocations!



## Metals

Metals Bend and Stretch

Metallic Bonds Allow Atoms to Move  
Easily

Different Crystal Structures Exhibit  
Different Properties

## Gold vs Iron

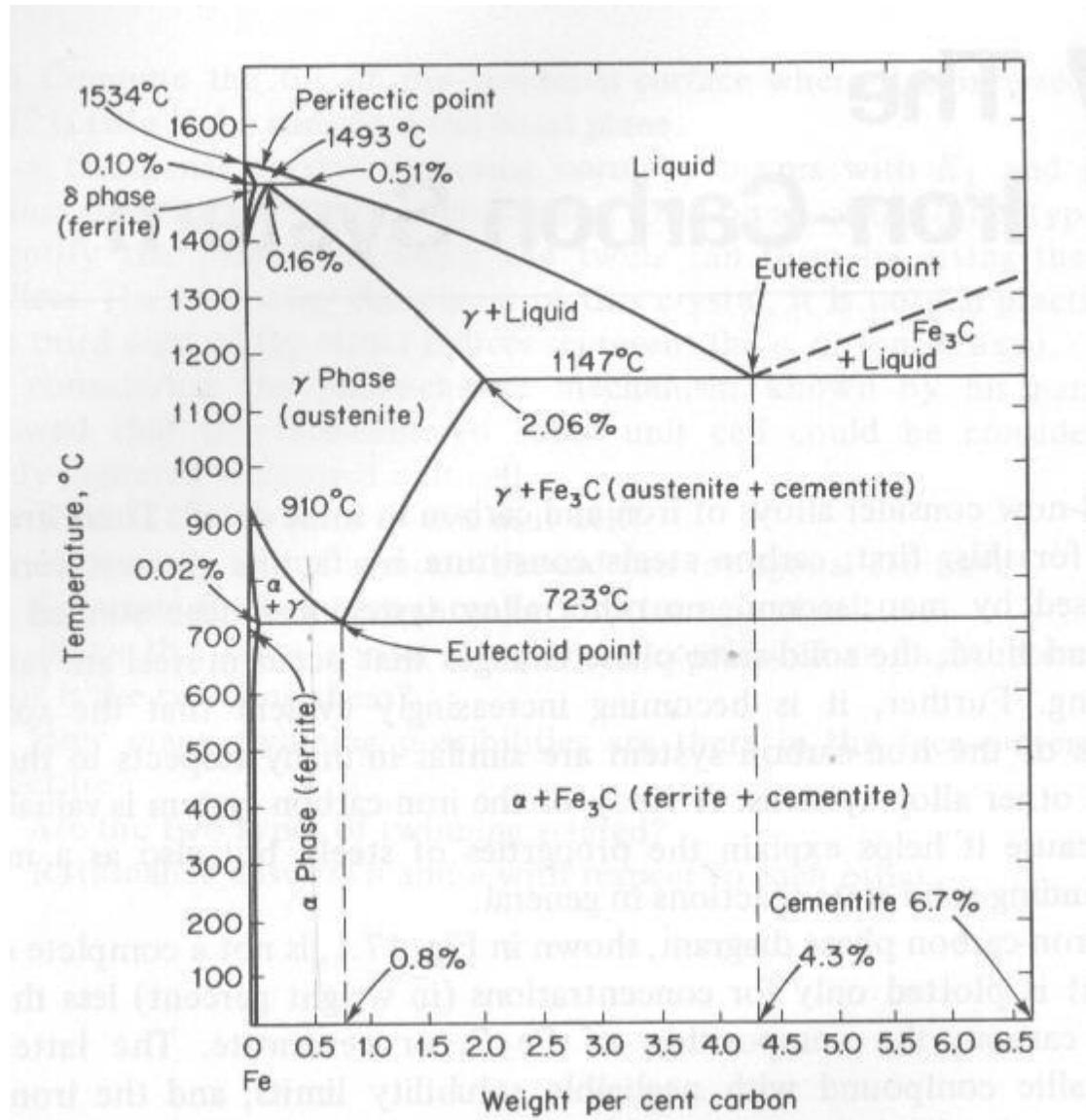
Gold Has FCC Structure: More Slip Systems,  
Thus More Deformable

Iron Has Different Properties Depending on  
Processing: Composition, Heat Treatment, etc.

Iron Can Be: FCC or BCC, Hard or Soft,  
Strong or Weak

- ◆ Adding Small Amounts of Other Atoms Can Significantly Change Properties!

# Structure – Processing -Properties

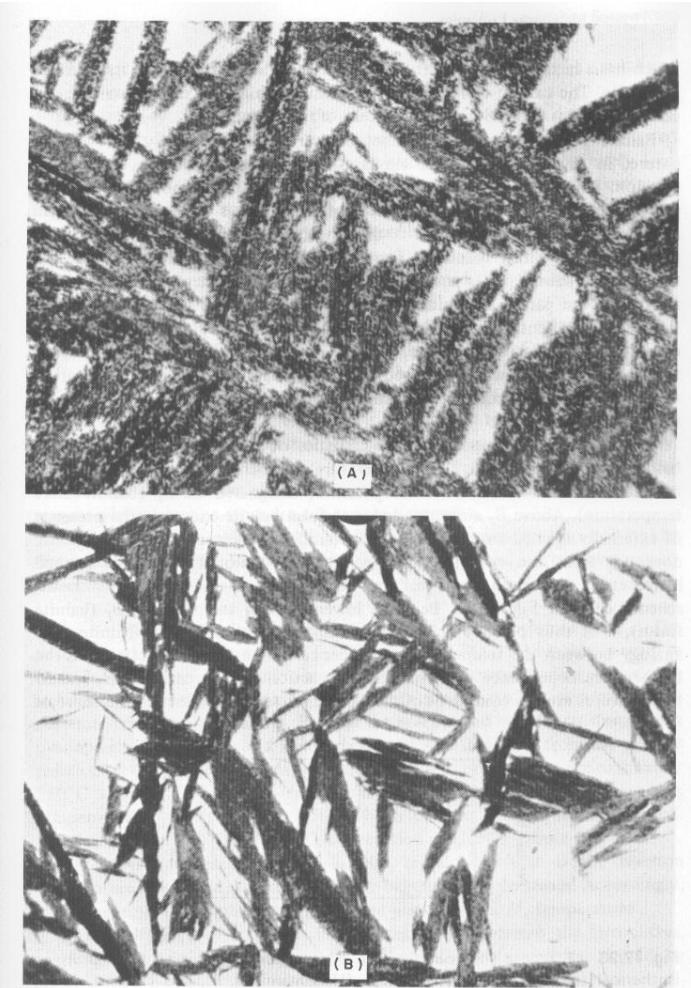


**Phase Diagrams show the relationship between phase, temperature, and composition.**

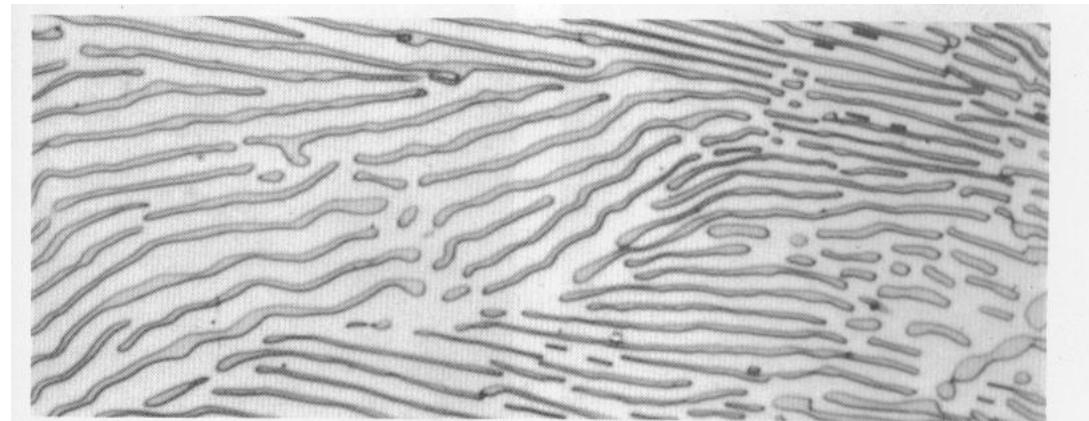


# Structure – Processing -Properties

## Microstructures affect Properties!



**Bainite**



**Pearlite**  
**Martensite**

## Horse Shoes

What Properties Make a Good Horse Shoe?

The Blacksmith Heats the Steel & Forms the Shoe, Next Heats the Shoe to Cherry Red, Then Quenches It

Hard Surface and Soft Interior Result Yielding Good Wear Resistance and Shock Absorption



# Properties

## Mechanical Properties

Strength (Yield and Tensile)

Poisson's Ratio

Toughness

Elongation

Fatigue Resistance

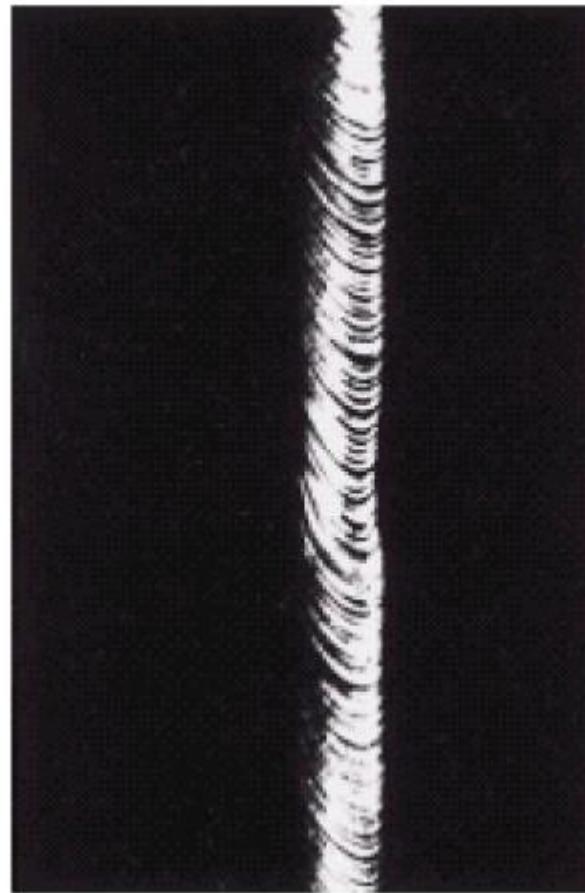
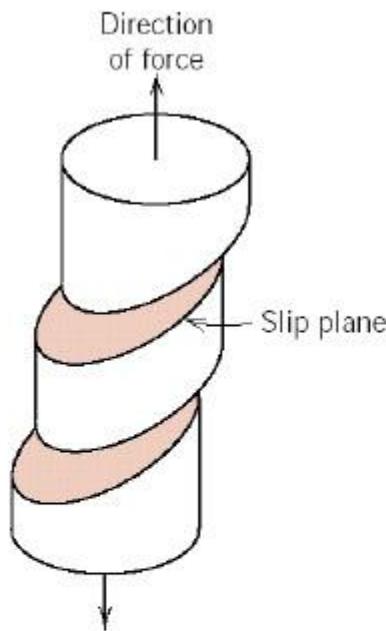
Wear Resistance

And Others

Do Metals, Ceramics, and Polymers Behave  
Differently? Why?

# Properties

## Slip in Tension Tests



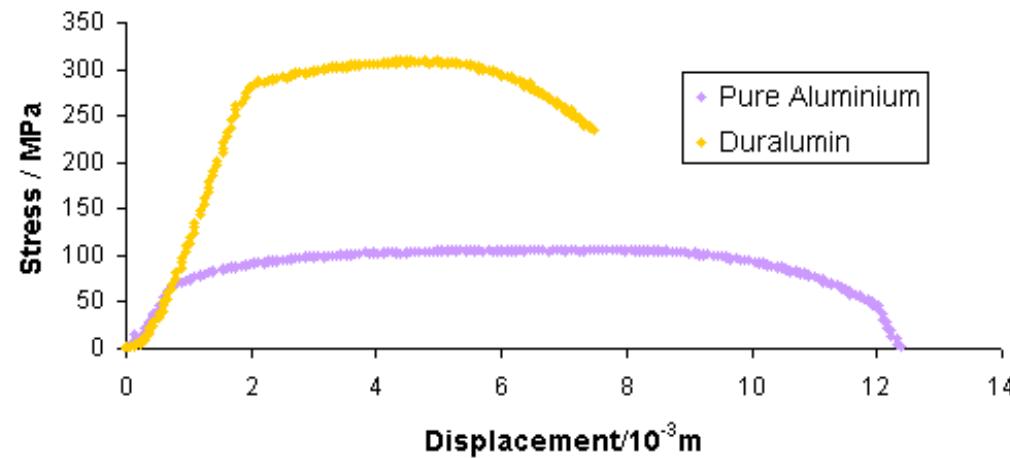
Slip in a zinc  
single crystal  
Elam 1935

From Callister 6e  
Figs 7.8, 7.9

# Properties

## Duralumin vs. Aluminum

Graph showing stress against displacement for aluminium and duralumin samples in tensile tests



Duraluminum – Al-Cu-Mg-Mn Age Hardened Alloy,  
discovered in early 1900's (2000 series of Al Alloys)  
Note Differences in YS, Elongation, UTS, etc.

# Properties

## Dislocation Motion Affects Strength

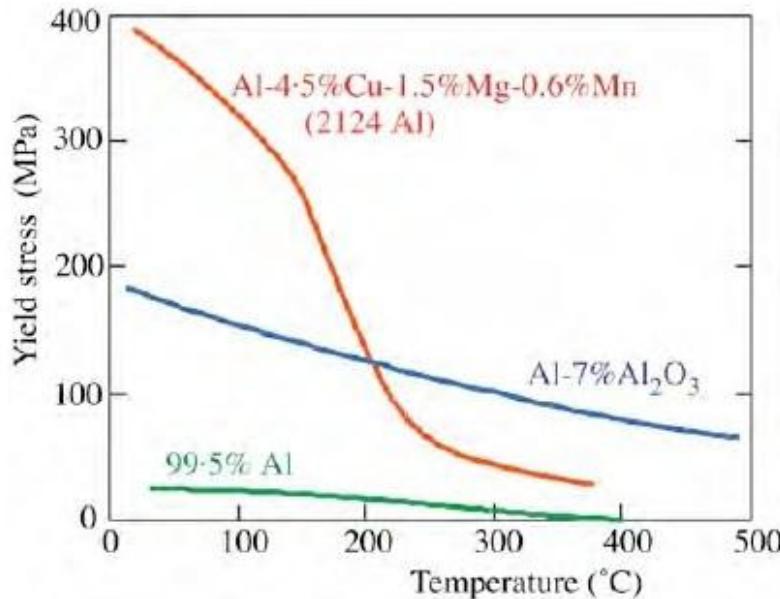
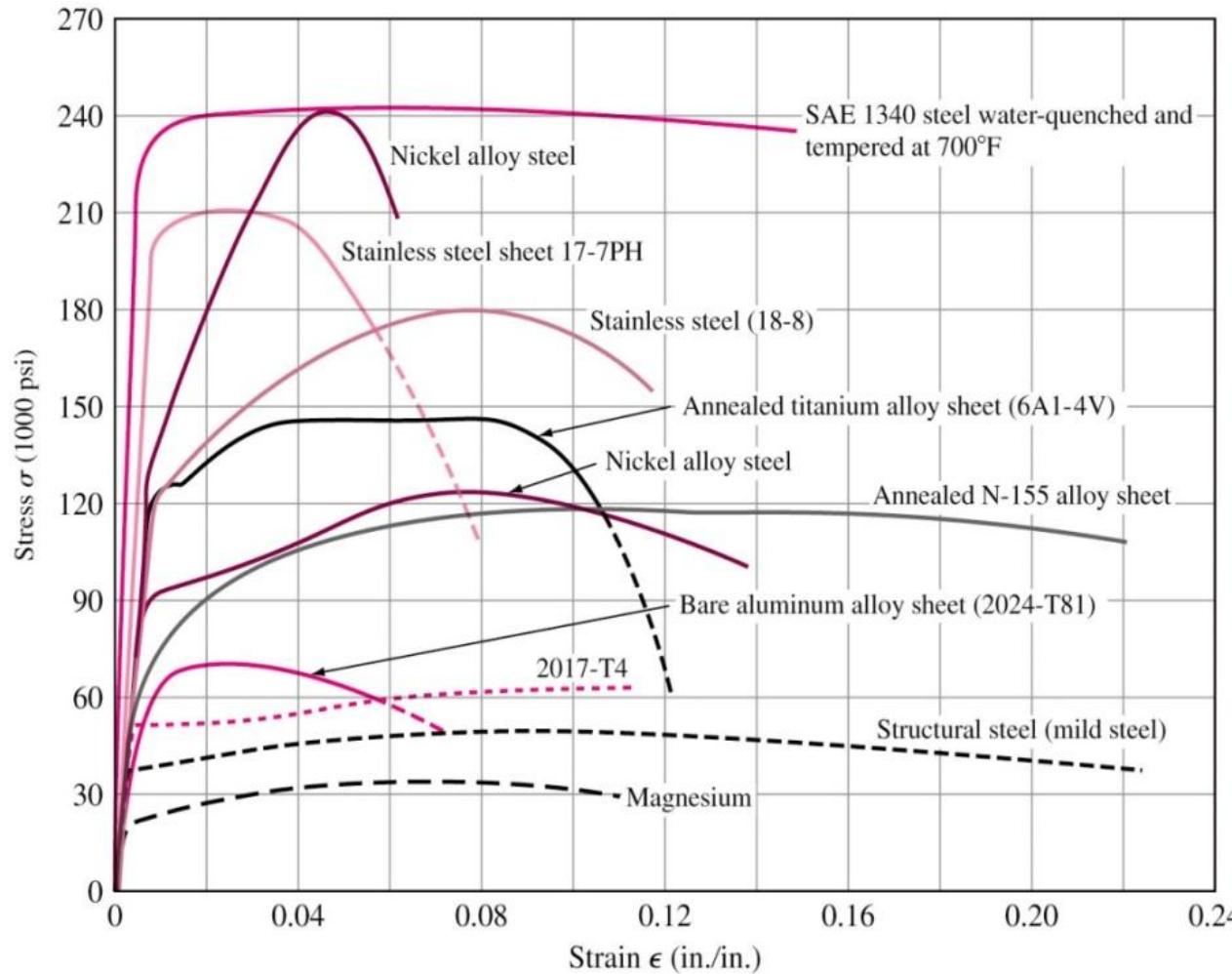


Fig.7.4 Yield stress as a function of temperature for commercial purity aluminium and for typical precipitation-hardened (2124) and dispersion-strengthened Al alloys.

# Properties

## Stress – Strain Curves





# Properties

## Thermal Properties

Thermal Conductivity

Coefficient of Thermal Expansion

Heat Capacity

Creep

Do Metals, Ceramics, and Polymers Behave  
Differently? Why?



# Properties

## Chemical Properties

Corrosion

Changes in Chemical Composition

Reactions with Environment

Do Metals, Ceramics, and Polymers Behave  
Differently? Why?



# Properties

## Electrical & Optical Properties

Conductivity & Resistance

Magnetic

Ferroelectric and Piezoelectric

Transparency, Translucency, Opacity

Do Metals, Ceramics, and Polymers Behave  
Differently? Why?



# Properties

## Synergistic Effects

Materials are subject to environments where all properties are affected.

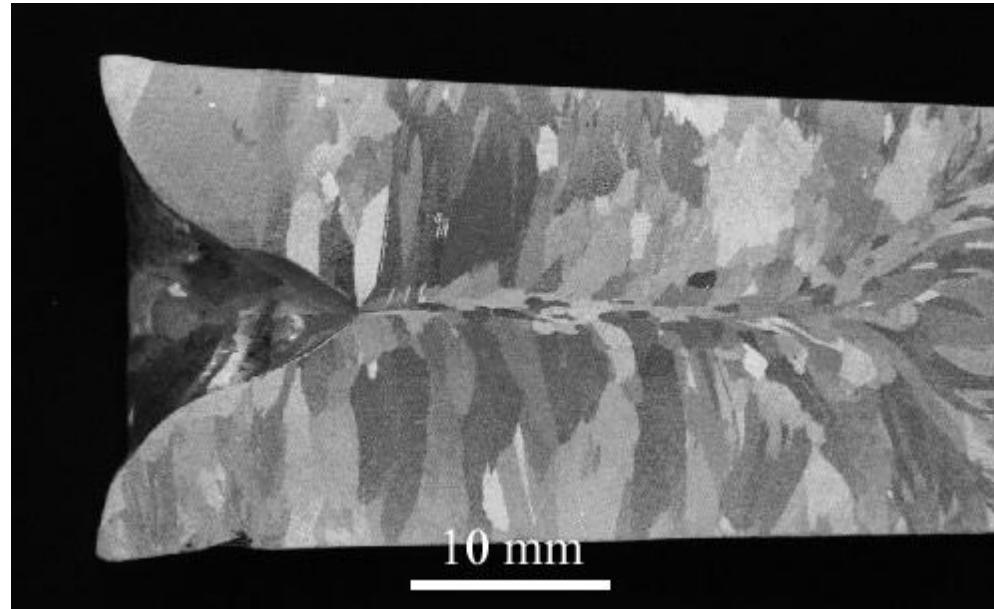
Strength at high temperature in a corrosive environment!



<http://www.met-tech.com/images/preheater-tube-failure-1.jpg>

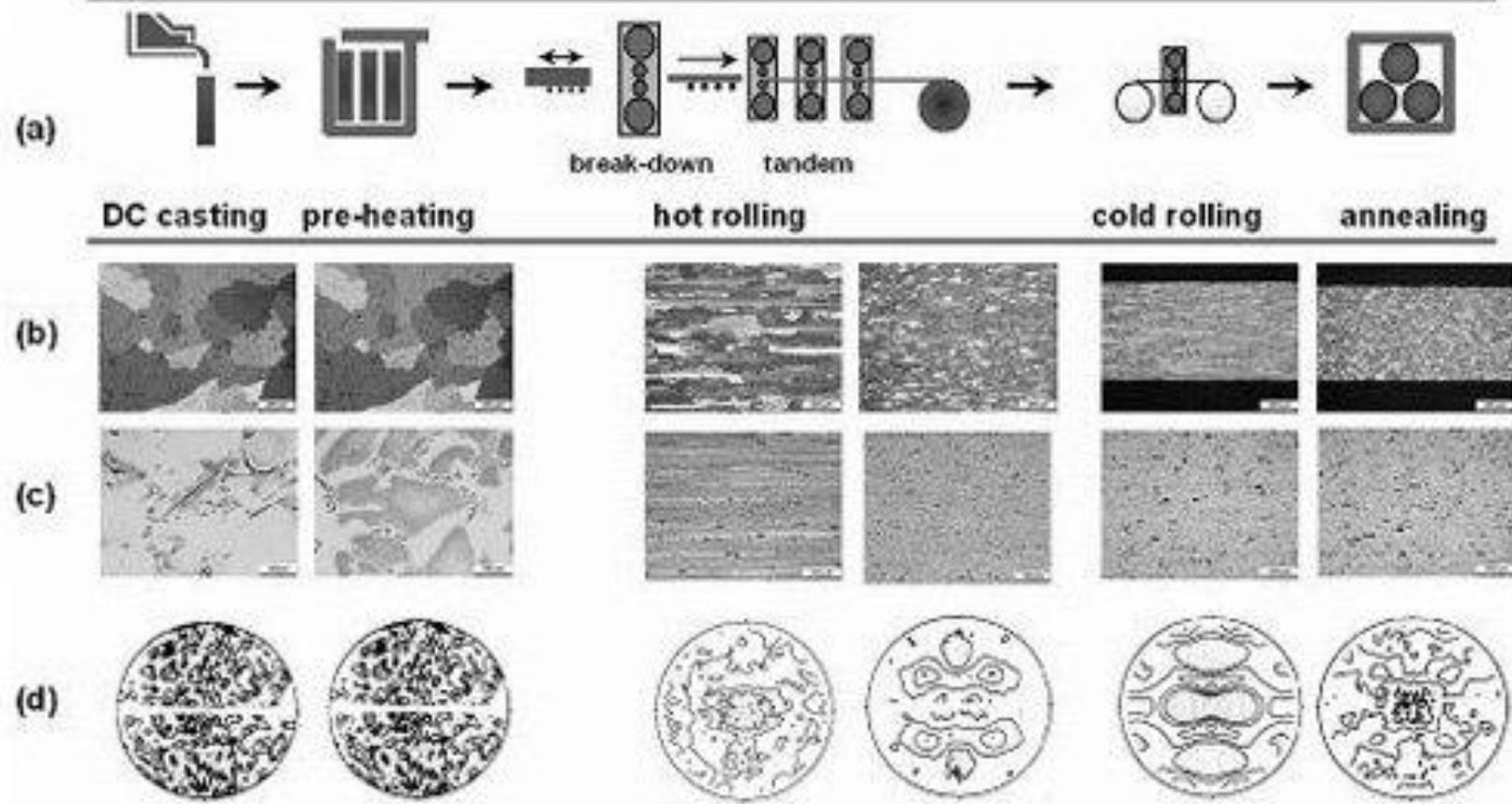
# Processing

## Solidification – Casting of Metal



# Processing

## Processing Affects Microstructure





# Processing



Microstructure  
Reveals  
Processing  
Methods





## Forming: Deep Drawing

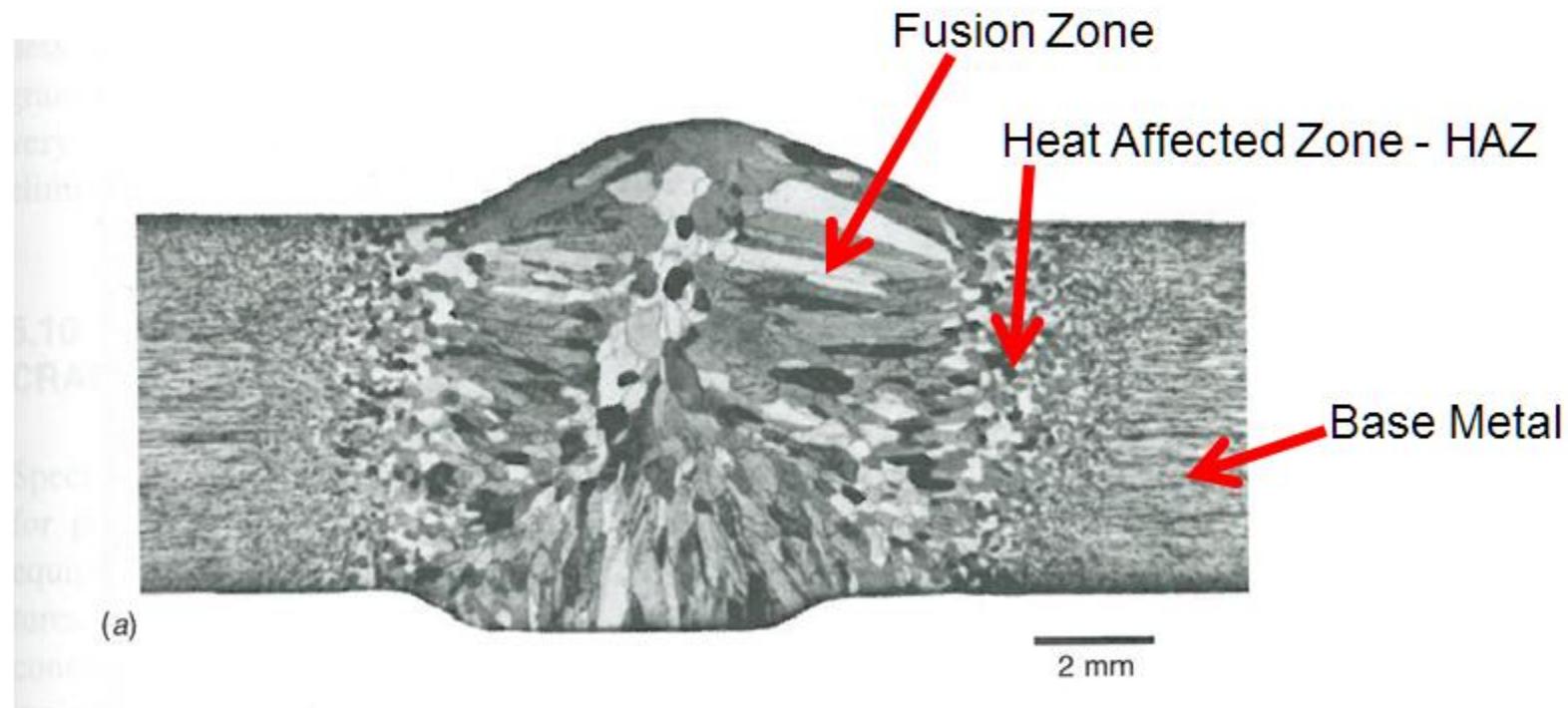


<http://www.trans-matic.com/FilesCustom/HTMLEditor/images/Web%20page%20pics%202.jpg>

# Processing

## Joining: Welding

One Pass GTAW (TIG) weld in hot rolled 436 SS with 308 filler



Lippold, Welding Metallurgy & Weldability of Stainless Steels, Wiley, 2005

# Reconstruction of a Can

## Basic Understanding of Processing-Structure-Properties of Metals

### Life-Cycle of the Aluminum Can



\*Courtesy of Novelis Corporation



# Resources

**Many Sources:**

**Professional Societies (ASM International,  
SME, ASME, STLE, etc.)**

**Videos on TV: Discovery, Science, Nat. Geo.**

**Web Sites:**

Making Euro Coins:

<http://asm.informz.net/z/cjUucD9taT0xODIzNzQ2JnA9MSZ1PTEwMTY4NjIxNDMmbGk9ODQzMDExNA/index.html>

Forging

<http://www.youtube.com/watch?v=tLRkOupbARM>