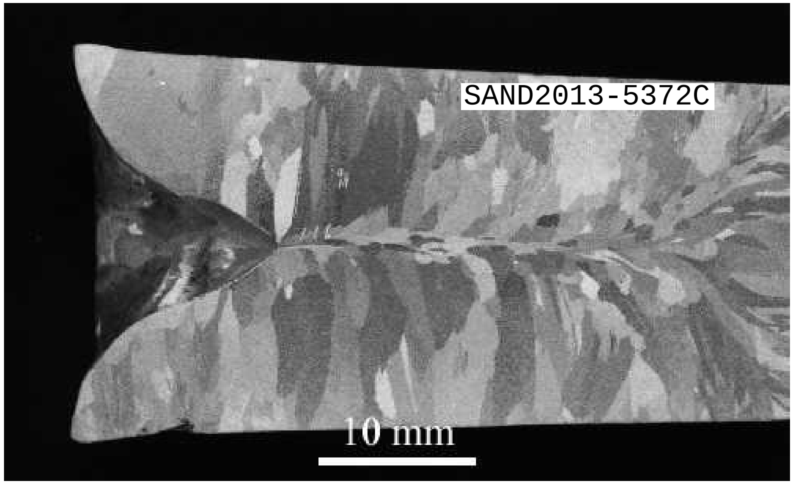
Lippold, Welding Metallurgy & Weldability of Stainless Steels, Wiley, 2005



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

Department 01832:

Coatings and Surface Engineering

(505) 284-5537

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.

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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**

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

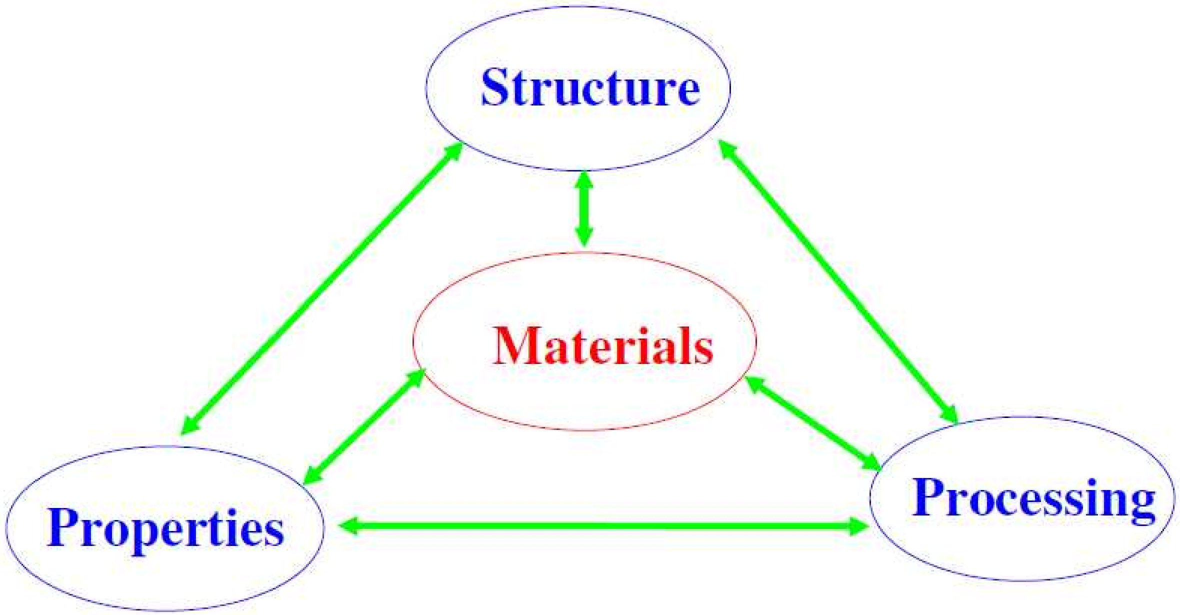
Traditional Areas: Metals, Polymers, Ceramics, Composites

New Areas: Biomaterials, Nanomaterials

Hot Topic: Additive Manufacturing

The Basics

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



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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

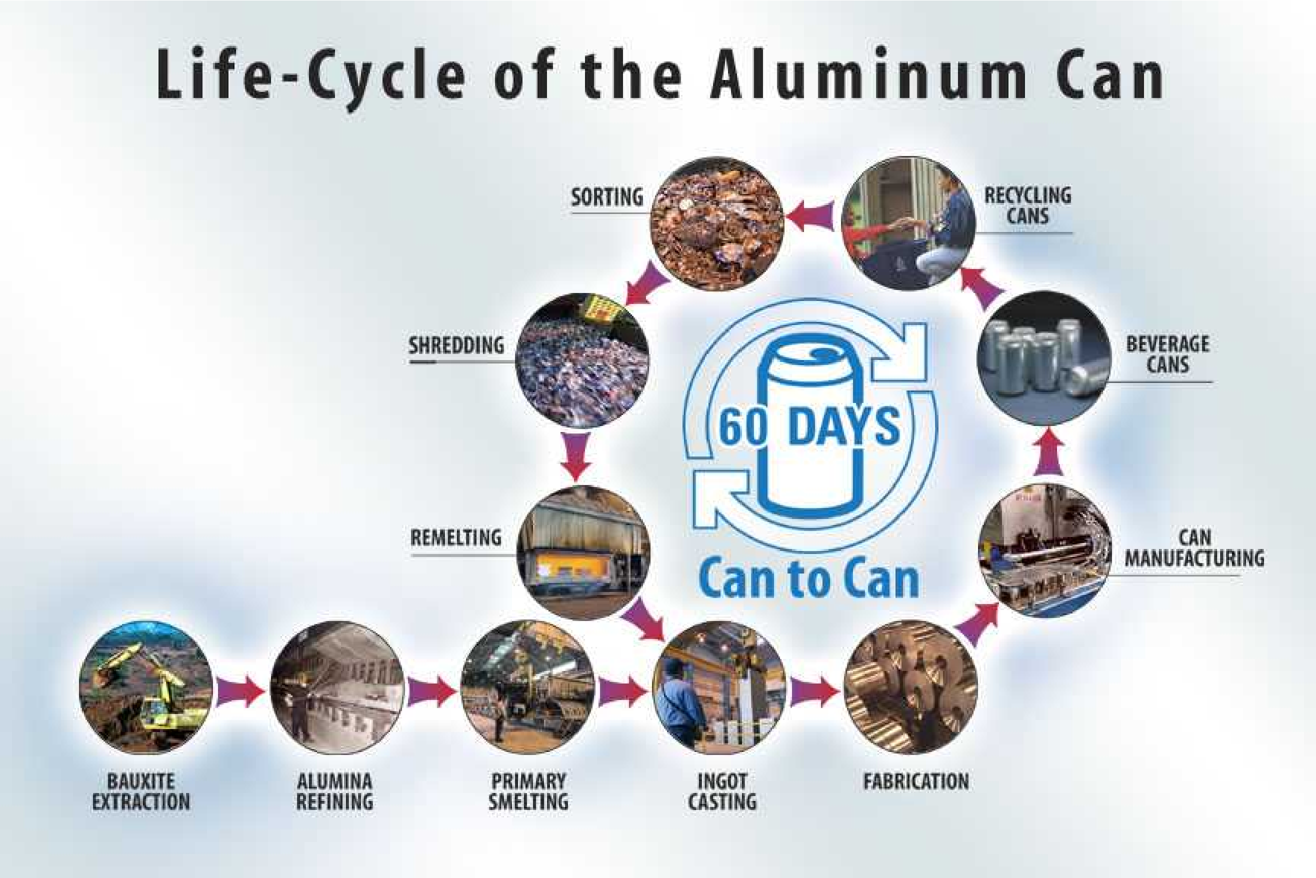
http://www.commodities-now.com/news/metals-and-mining/6994-global-steel-output-to-reach-157-bn-tons-2011.html

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
- 13th-14th Centuries – Arsenic, Antimony, Zinc, and Bismuth
- 16th 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 20th Century

Deconstruction of a Can

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



*Courtesy of Novelis Corporation

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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

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Extractive Metallurgy

Mining, Communition, Benefication

www.nr.usu.edu

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Aluminum Processing

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

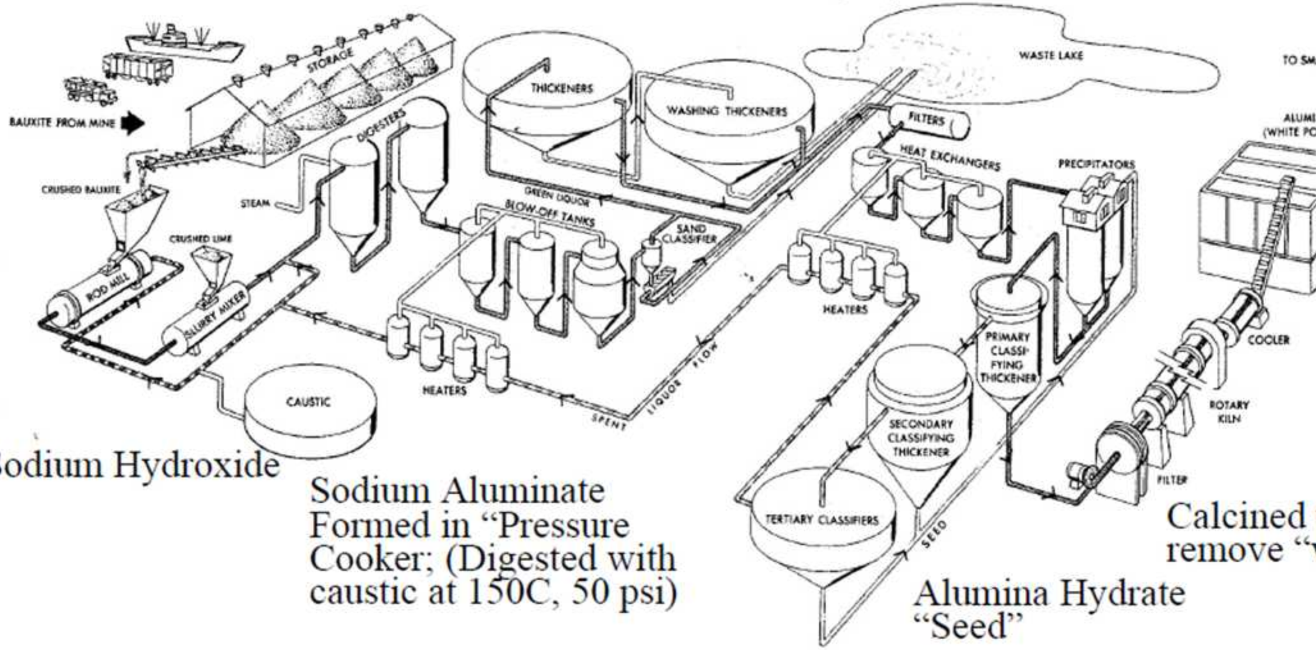
Al first extracted in early 1800's but very difficult

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

Aluminum Processing

Red Mud contains Fe, Si, Ti



Sodium Hydroxide

Sodium Aluminate Formed in "Pressure Cooker; (Digested with caustic at 150C, 50 psi)

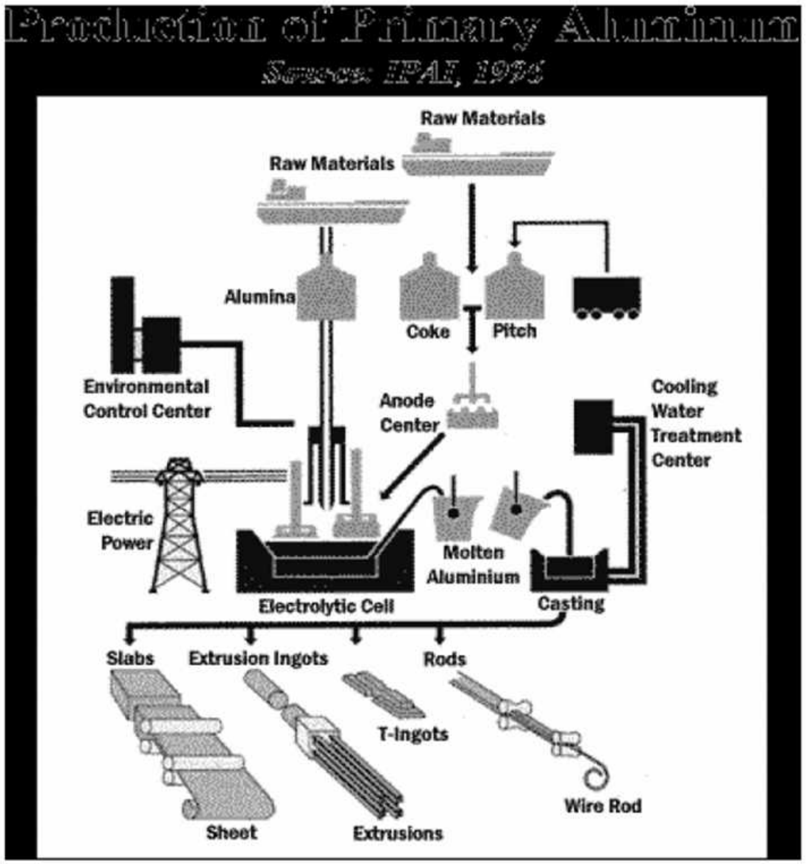
Alumina Hydrate "Seed"

Calcined to remove "water"

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

Reed, Introduction to Processing of Ceramics

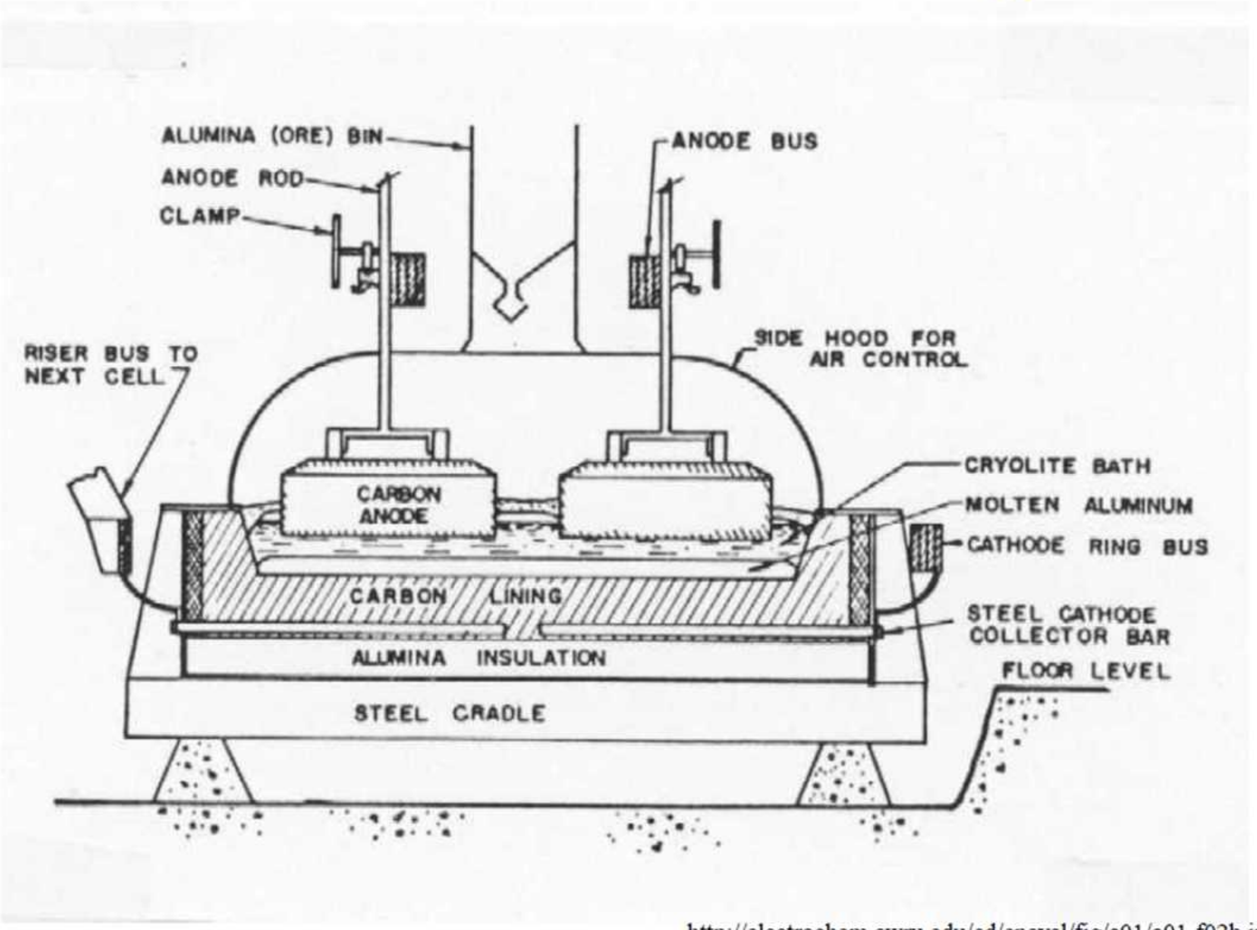
Aluminum Processing



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: 0.6Tm

Cold Working: RT-200C

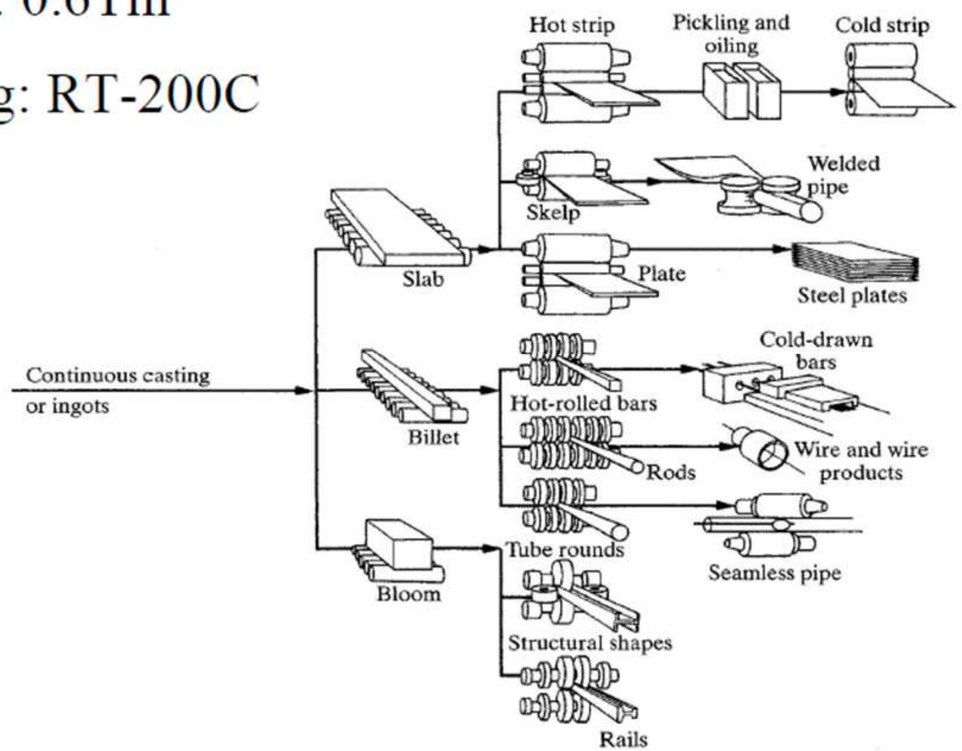
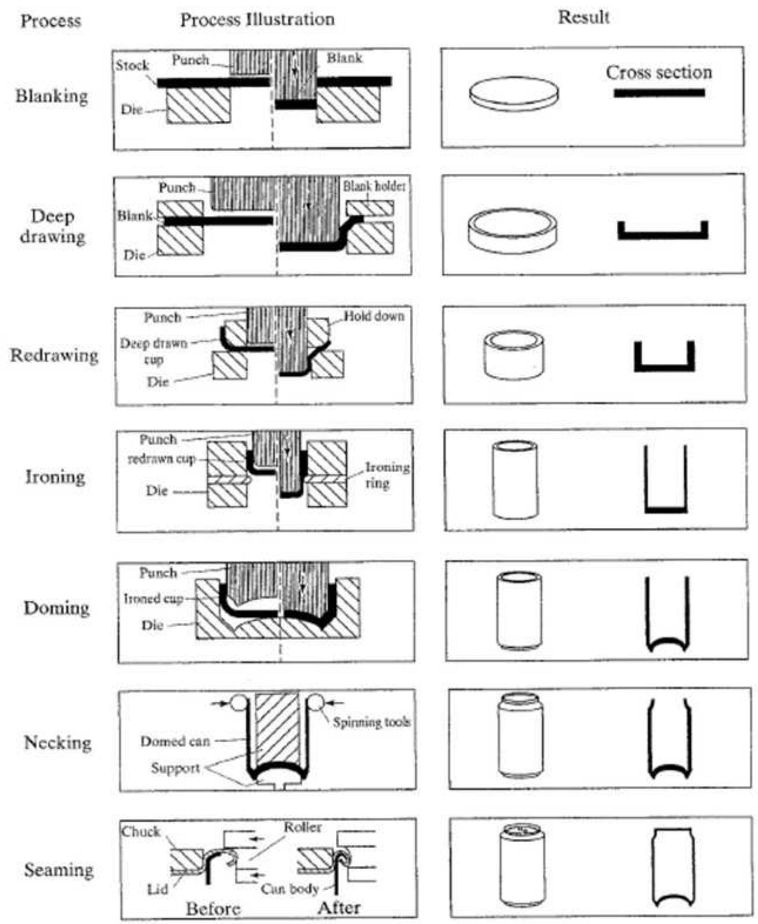


FIGURE 13.1 Schematic outline of various flat- and shape-rolling processes. *Source*: American Iron and Steel Institute.

Al Can Production

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



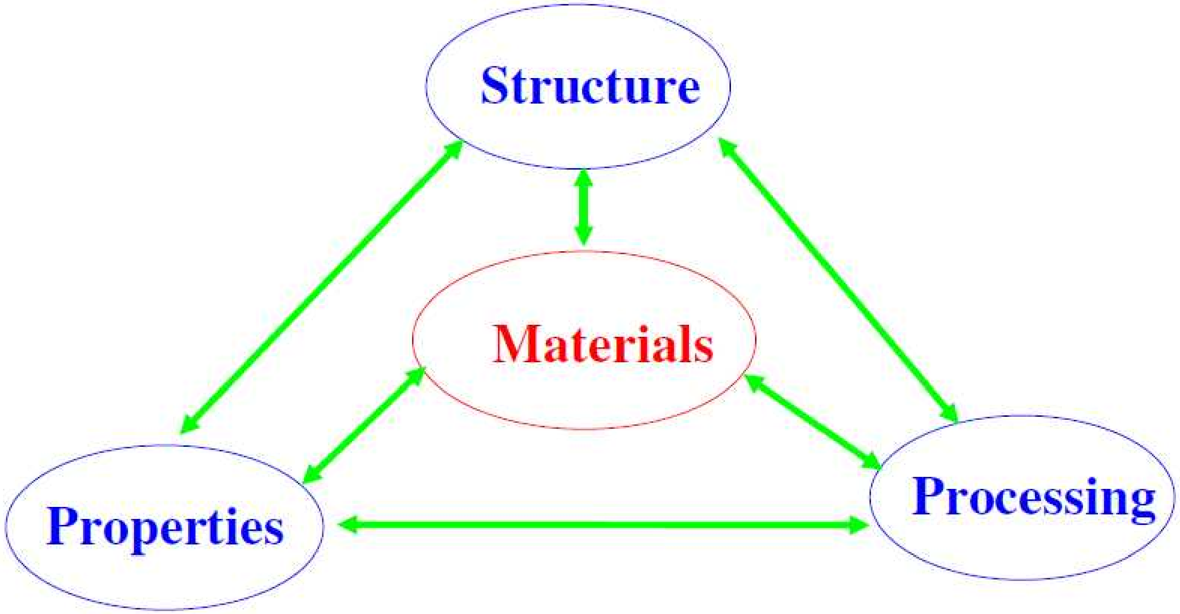
http://www.constellium.com/markets/packaging/food-and-beverage/can-body-stock

Sosurce: 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



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Structure

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

Structure

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.

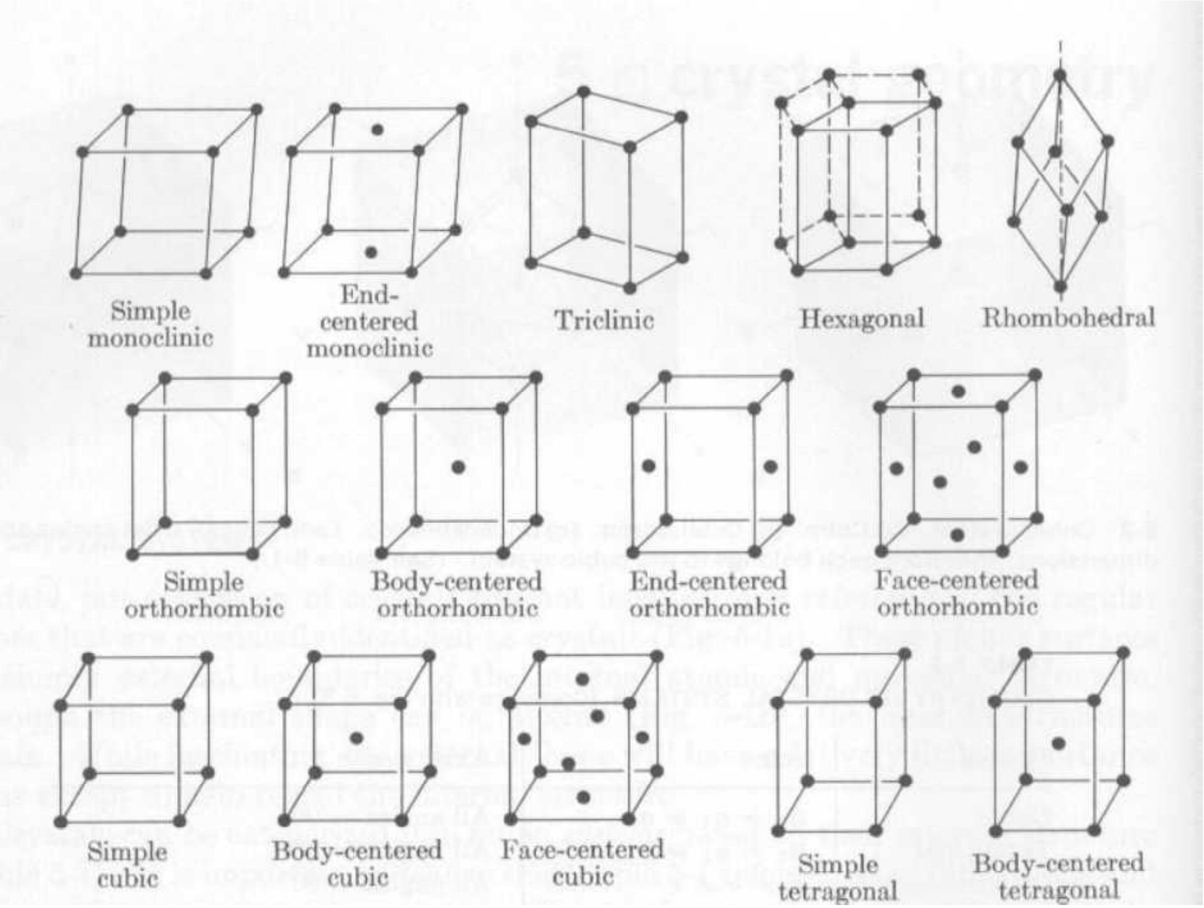
Crystal Structures

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



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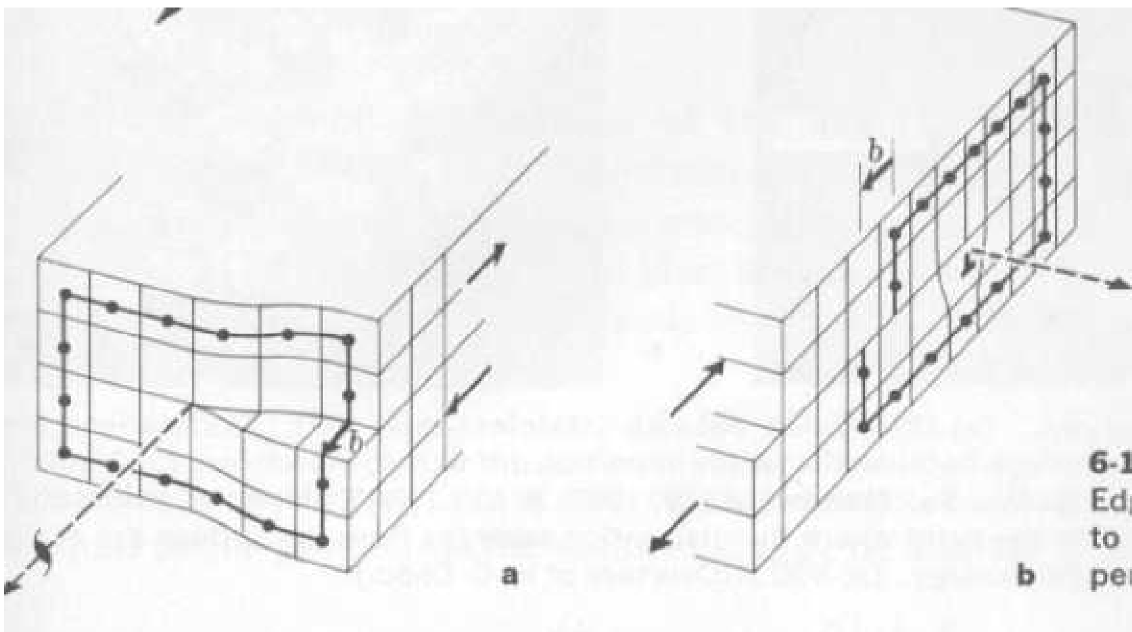
How Does Crystal Structure Affect Mechanical Properties?

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

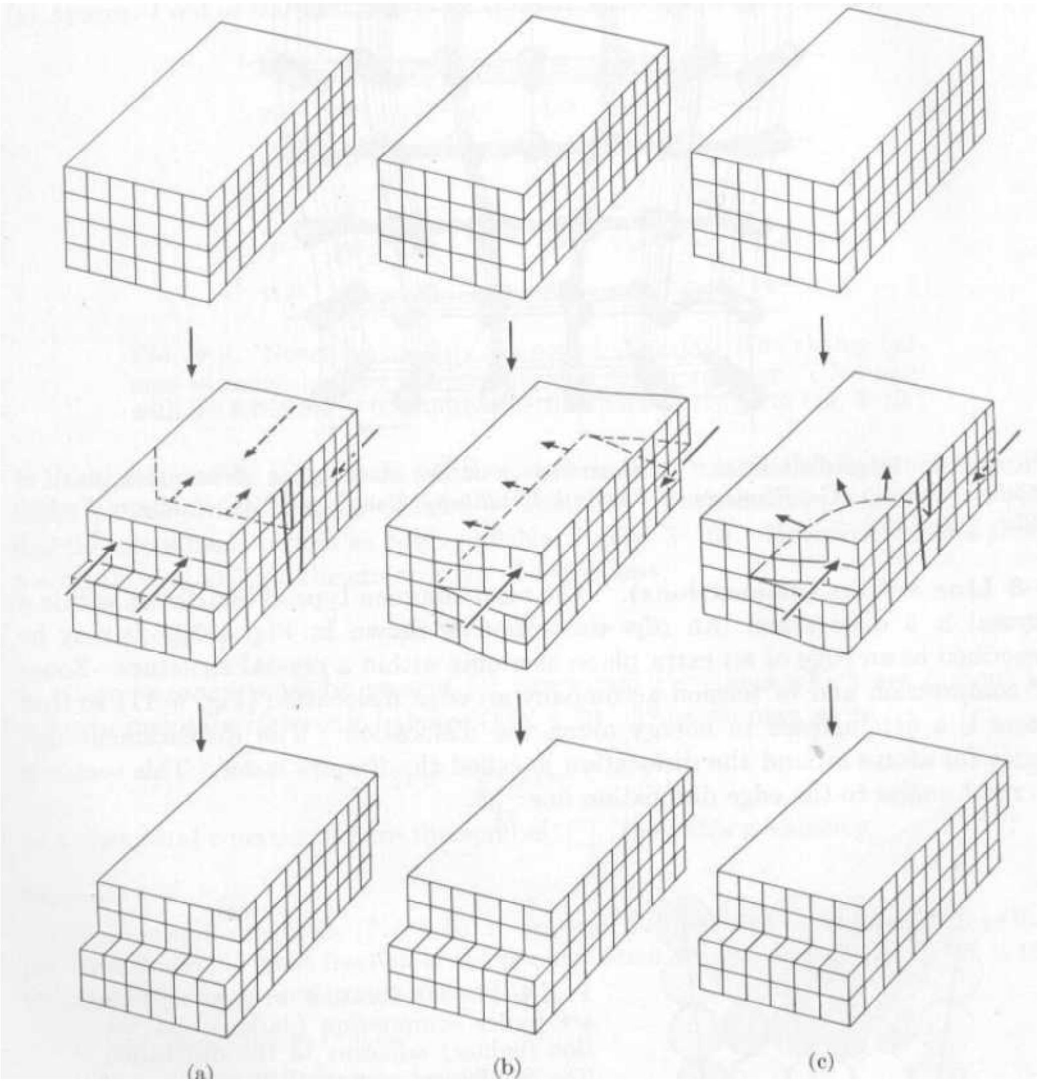
(How Atoms Move in the Crystal Lattice Subject to an Applied Load)

Dislocations – Extra Planes of Atoms in a Crystal Structure



6-11 Dislocations. (a) Screw. (b) Edge. The displacement is parallel to the screw dislocation but perpendicular to the edge dislocation.

Structure: Dislocations

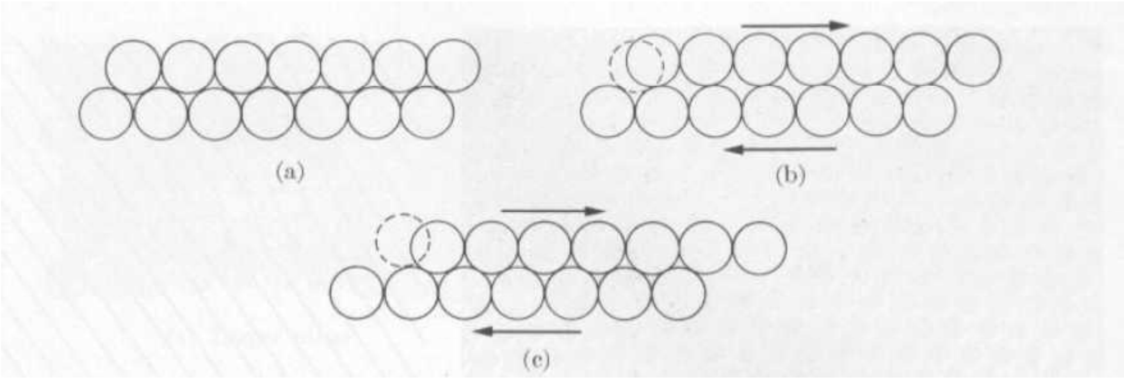


Slip Systems

Planes and Directions in Lattice Where Atoms Can Move Easily

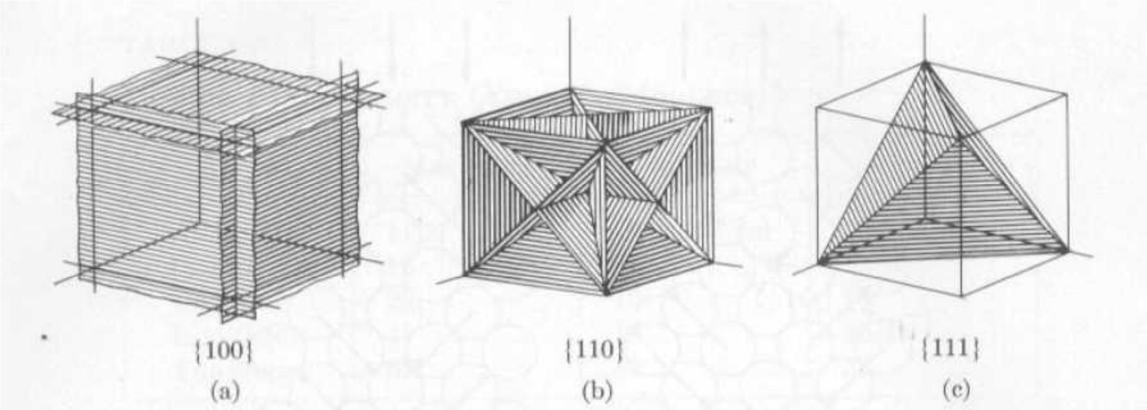
Where Atoms Are More Closely Packed Together, the Atoms Slide Across Each Other More Easily.

Structure: Dislocations



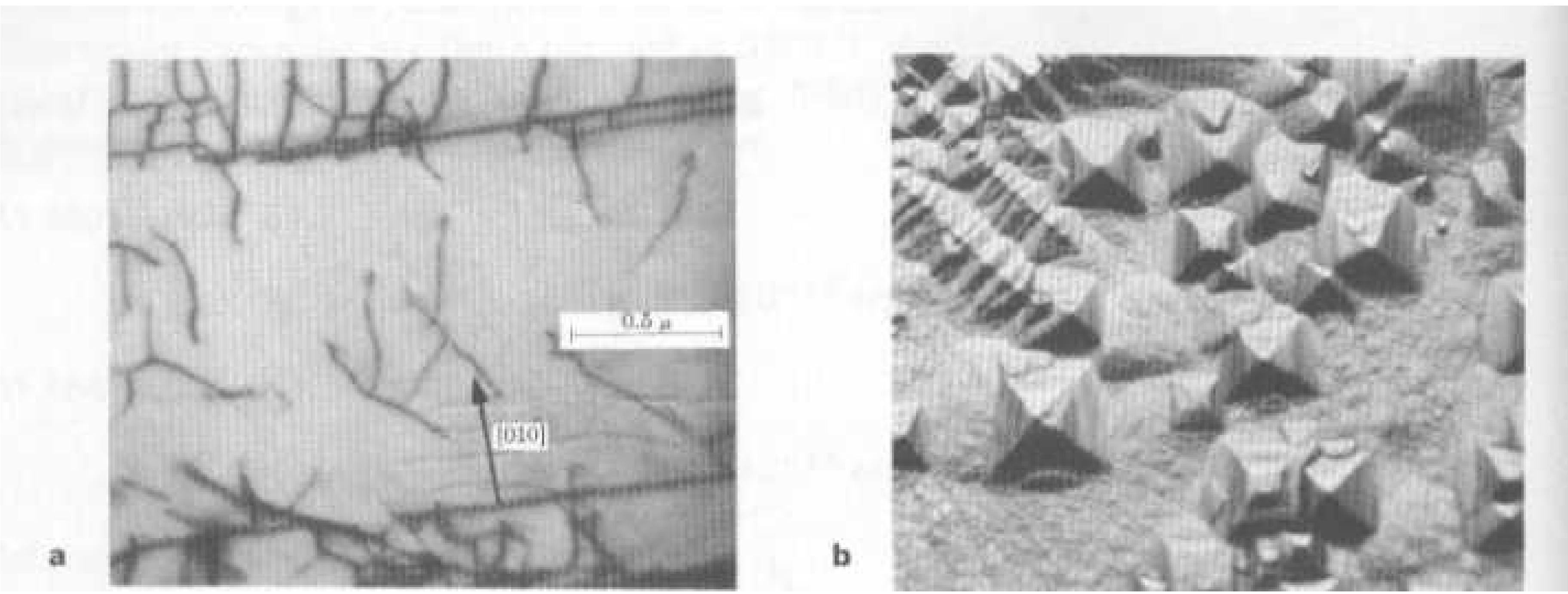
How Much Energy Is Required to Move Planes of Atoms?

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

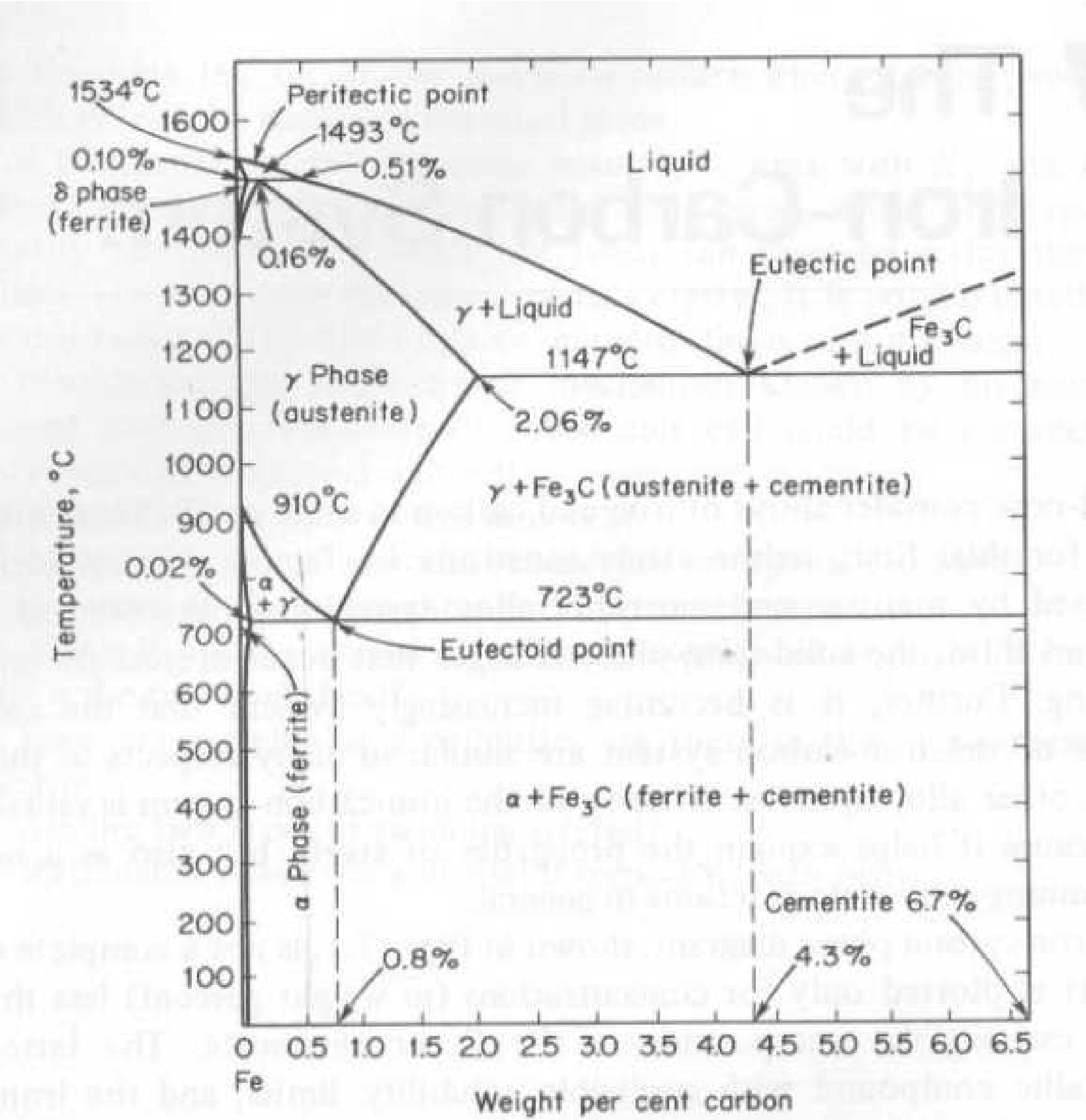
Gold Has FCC Structure: More Slip Systems,
Thus More Deformable

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!

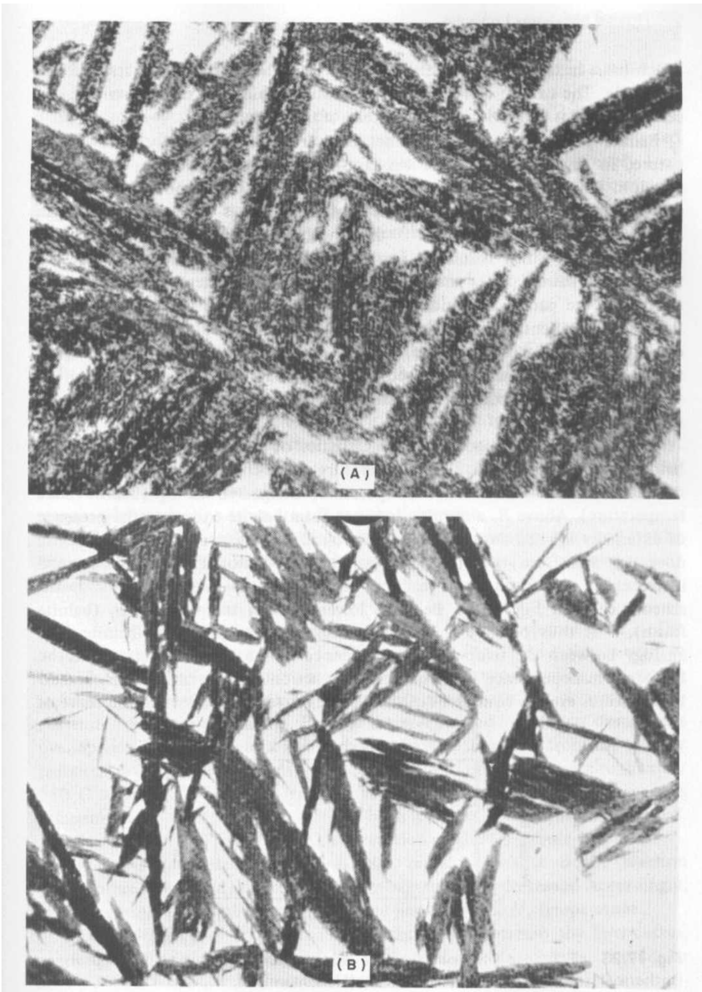
Structure – Processing -Properties



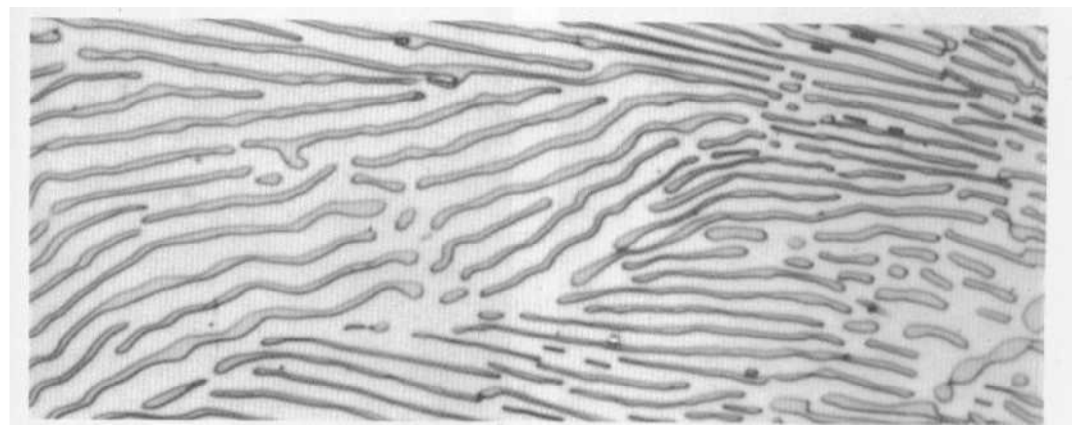
Phase Diagrams show the relationship between phase, temperature, and composition.

Structure – Processing -Properties

Microstructures affect Properties!



Bainite



Pearlite

Martinsite

Structure-Processing-Properties

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

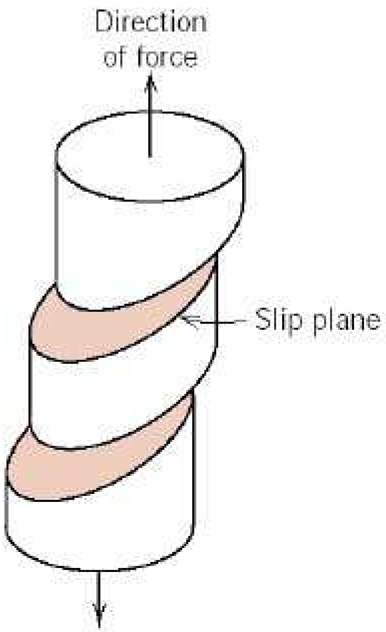
Fatigue Resistance

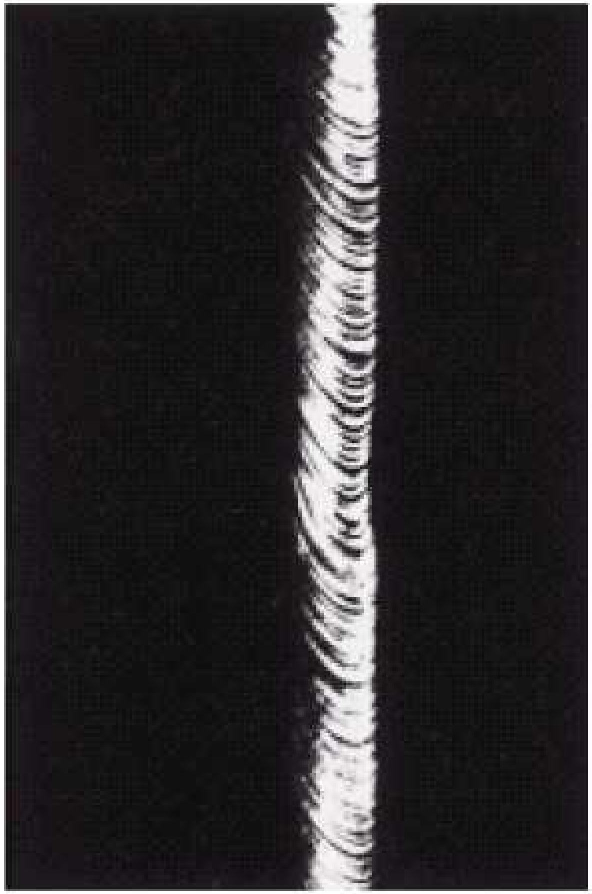
Wear Resistance

And Others

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

Slip in Tension Tests



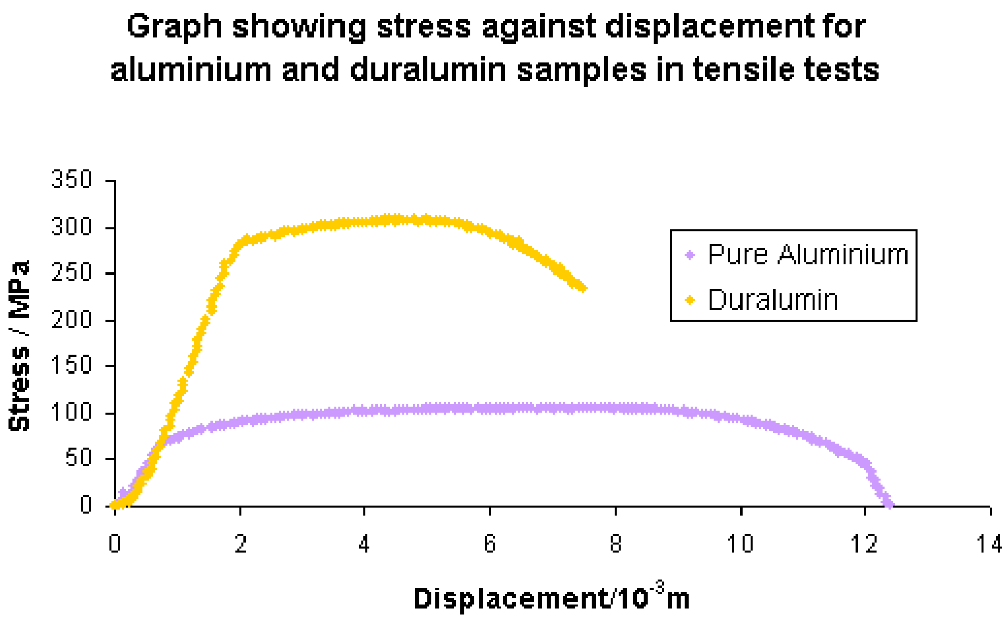


Slip in a zinc single crystal
Elam 1935

From Callister 6e
Figs 7.8, 7.9

Properties

Duralumin vs. Aluminum



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.

http://www.doitpoms.ac.uk/tlplib/mechanical-testing

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Properties

Dislocation Motion Affects Strength

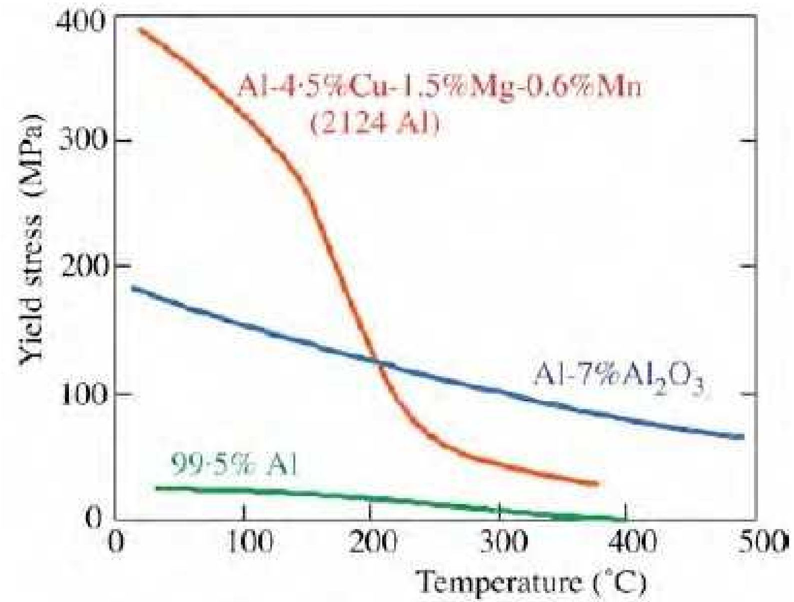

Fig.7.4 Yield stress as a function of temperature for commercial purity aluminium and for typical precipitation-hardened (2124) and dispersion-strengthened Al alloys.

www.msm.cam.ac.uk/Teaching/matmin1a/courseE/EH.pdf

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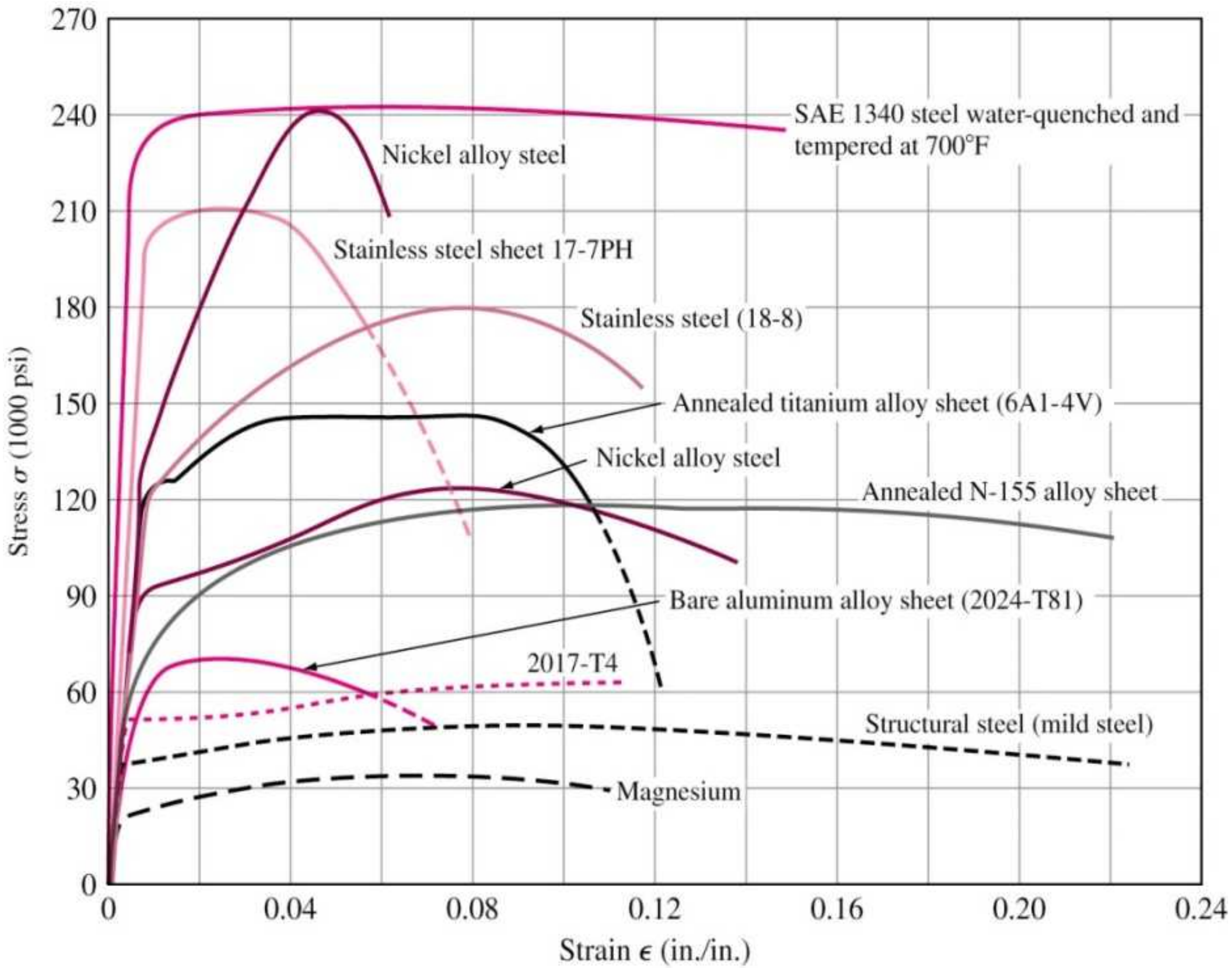
Properties

Stress – Strain Curves



Smith – Foundations of Materials Science

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?

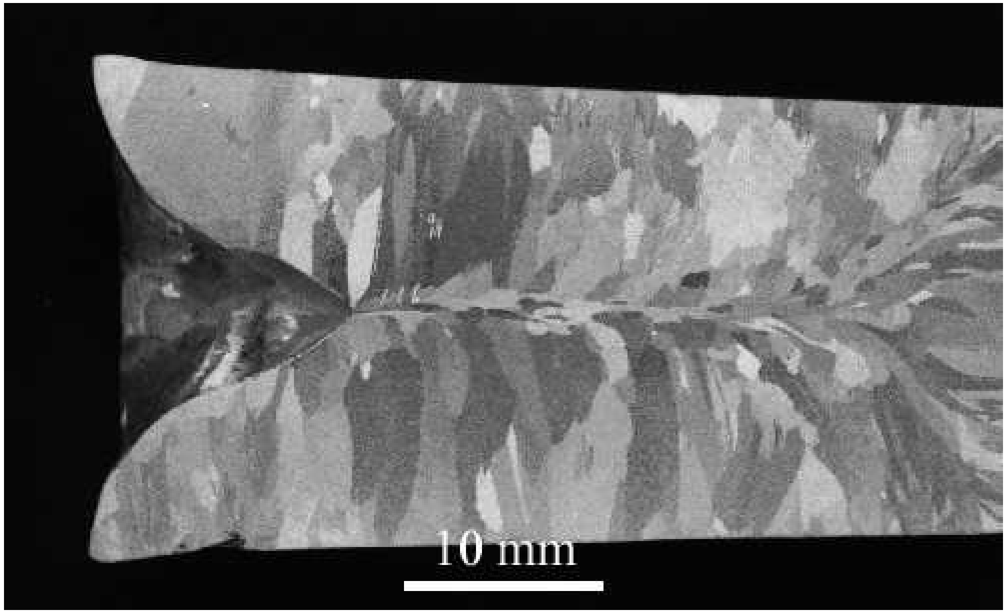
Properties

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

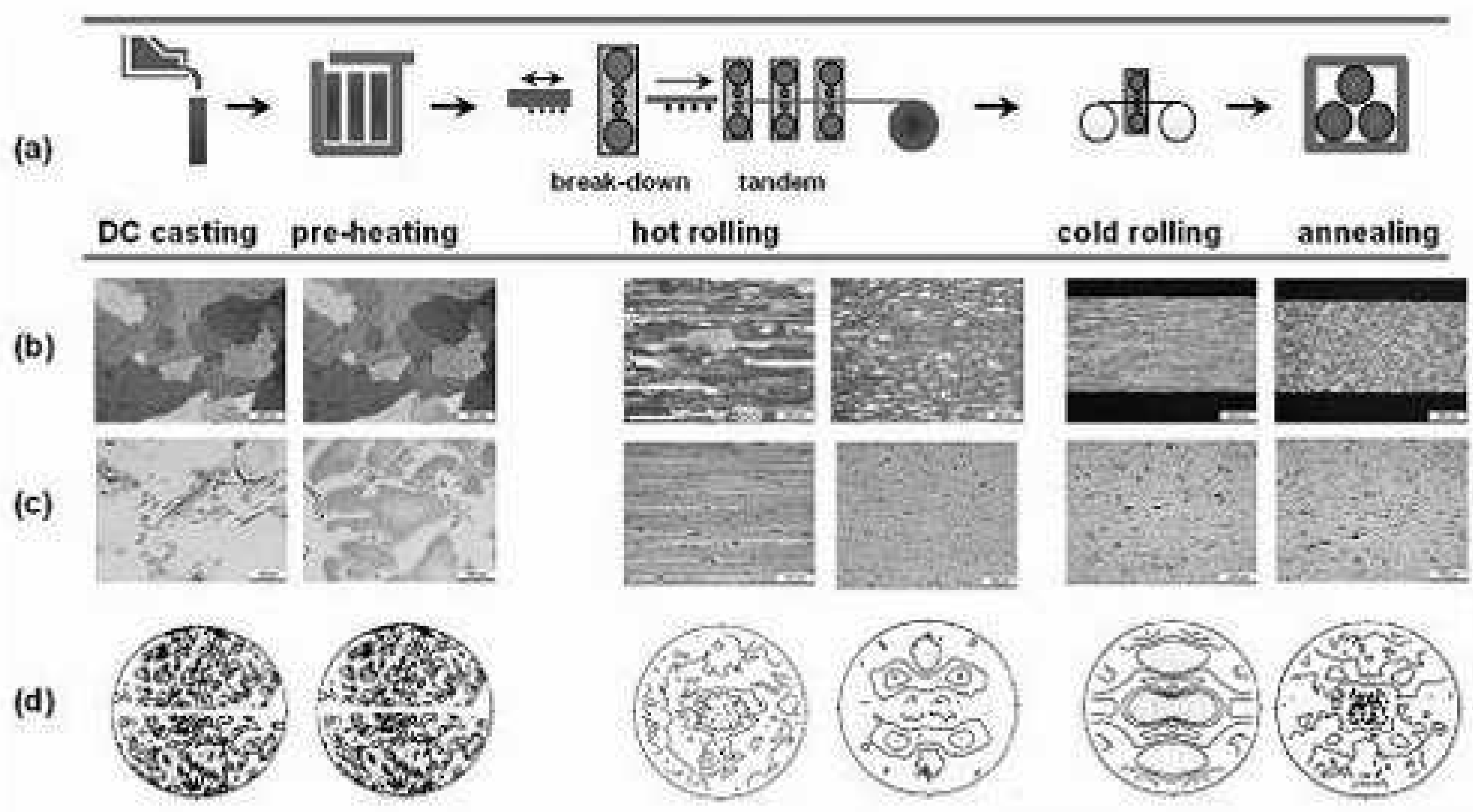
Solidification – Casting of Metal



http://www.doitpoms.ac.uk/miclib/full_record.php?id=615

Processing

Processing Affects Microstructure



http://img.alibaba.com/img/news/10/00/69/42/1256022846815_us_backyard1_1983.jpg

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Processing

Microstructure
Reveals
Processing
Methods

www.physicsforums.com/showthread.php?p=1244076

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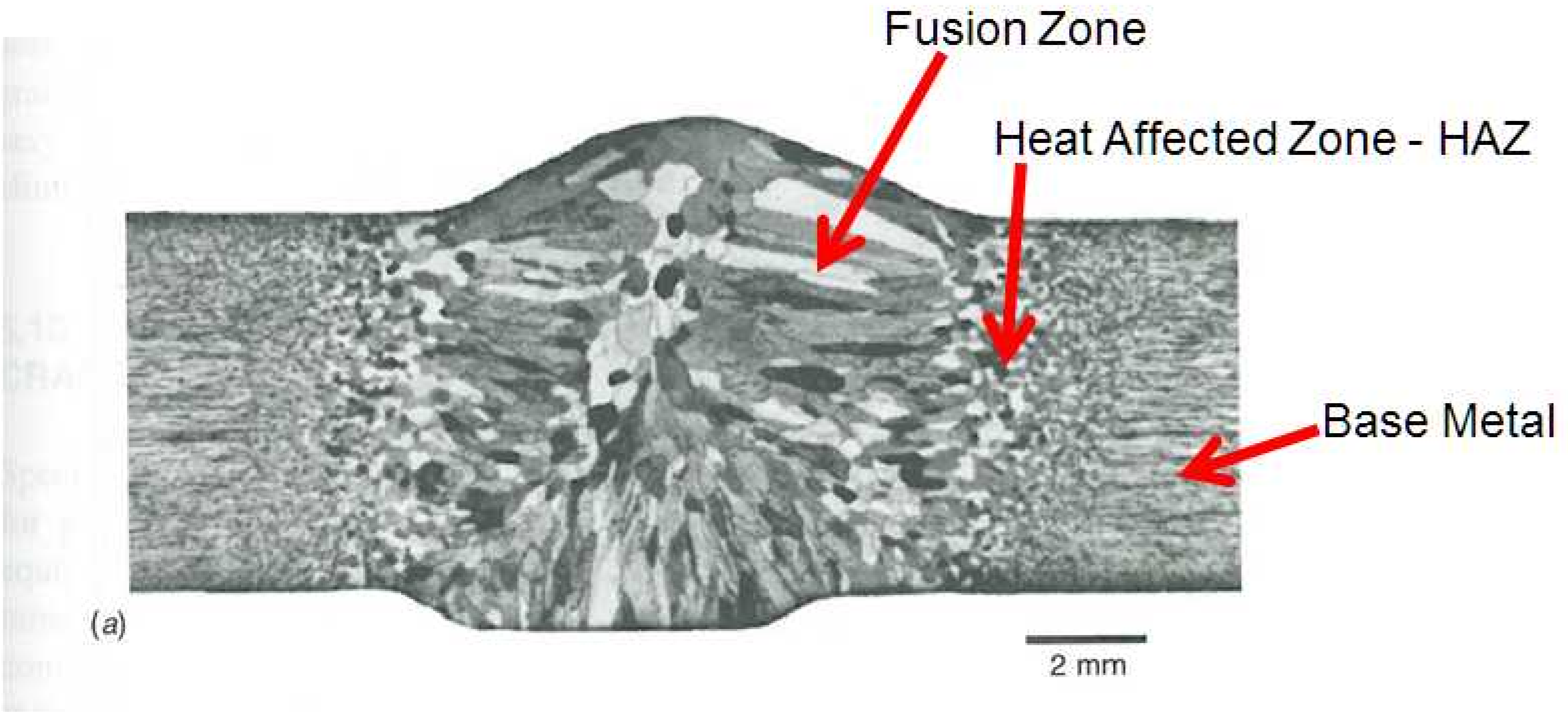
Forming: Deep Drawing

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

Joining: Welding

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



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

Processing

Joining: Soldering using Exothermic Foils

Process for Joining metals by melting and flowing a filler metal into the joint

Soldering <400°C

Brazing >400°C

Both have been used since ~ 4000 BCE

Exothermic Foils or Reactive Multilayers provide the heat source!

Reactive multilayers are useful for applications requiring localized heating (e.g., joining).

Early work on multilayers:

Prentice US Patent 4,158,084 (1979).
Floro J. Vac. Sci. Tech. A (1986).
Makowiecki US Pat. 5,381,944 (1995).
Barbee, Weihs US Pat. 5,547,715 (1996).

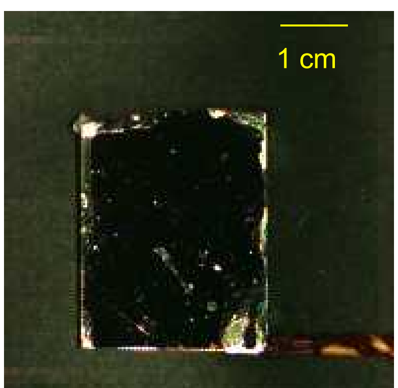
Applications:

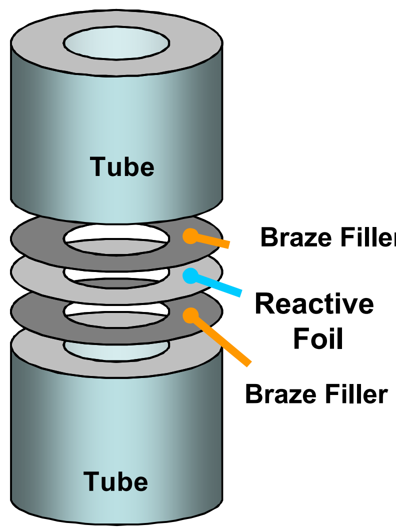
Joining, Soldering,
Lid seal, MEMS.

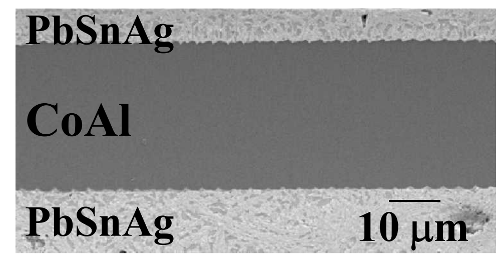
Key Properties:

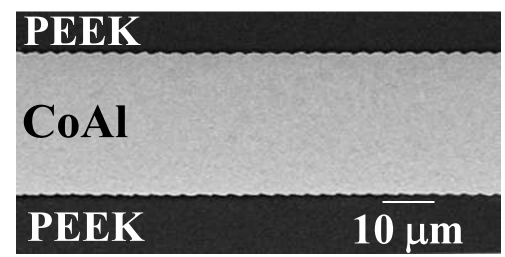
Stored chemical energy
Ignition at a point
Self-propagating Synthesis
Structure and Morphology

Movie in plan view
Aluminum /Platinum









Joined assemblies using
Cobalt/Aluminum

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Several vapor deposition techniques (evaporation, sputtering) have been used in the past to fabricate reactive multilayers.

Typical design (not requirements):

- Two reactant species
- Single, out of plane periodicity
- 2-1,000 reactant layers
- Total thickness: 0.25-150 μm

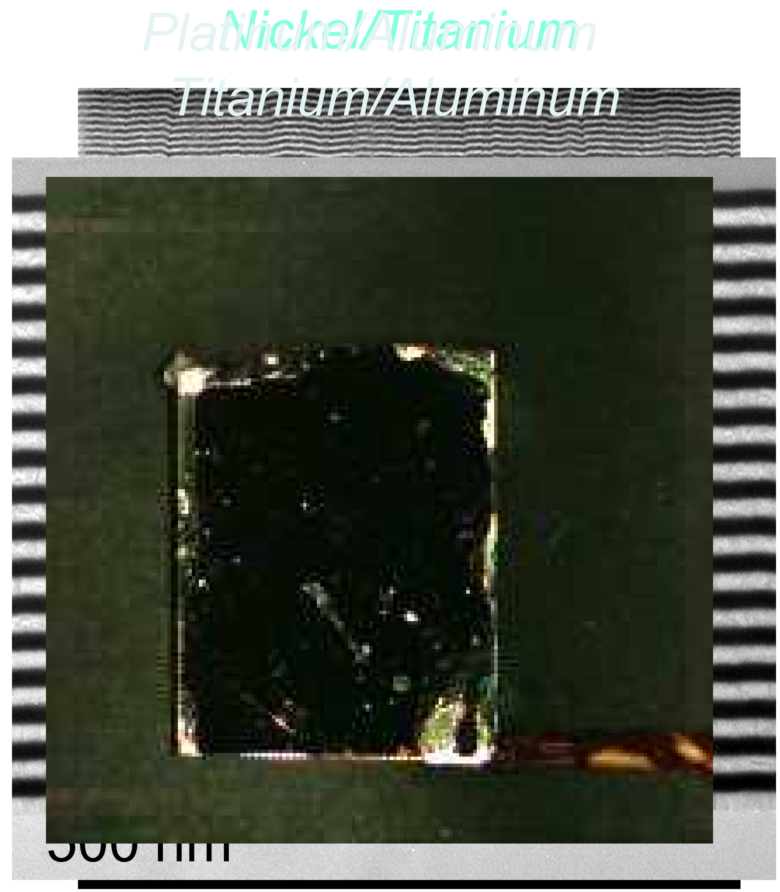
• Reactant pairs generally have a large heat of reaction, ΔH_o:

Ti/2B	: - 4.8 kJ/g
Al/NiO	: - 2.2 kJ/g
Co/Al	: - 1.4 kJ/g
Al/Pt	: - 0.9 kJ/g
Ni/Ti	: - 0.6 kJ/g

compare: TNT ΔH_o = - 4.18 kJ/g

• Reference previous work (multilayers)

Prentice US Patent (1979).
Floro J. Vac. Sci. Tech. A (1986).
Makowiecki US Pat. (1995).
Barbee, Weihs US Pat. (1996).



Multilayers in XS by TEM

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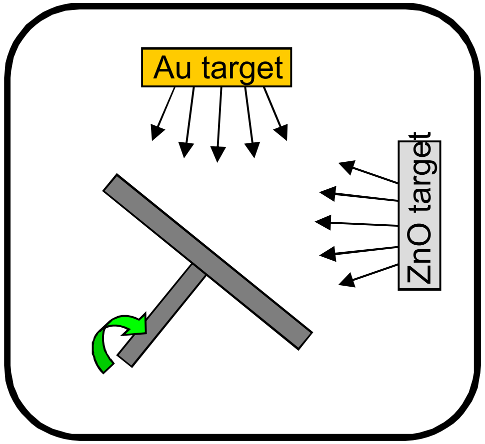
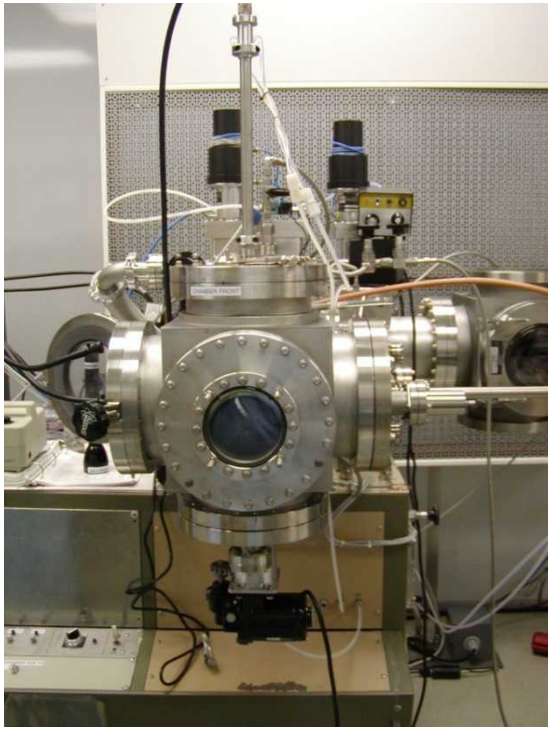
Sputter Deposition is Used to Make the Foils

Substrate at 45°
to both deposition
fluxes



Sputter Co-Deposition System

Sputter guns at 90°

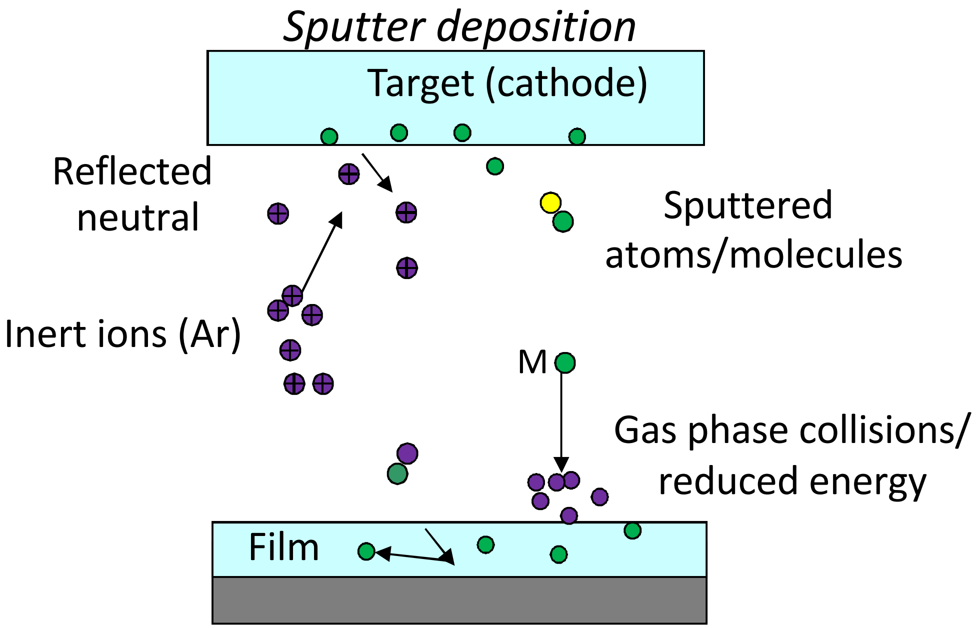


Two 2” sputter targets

Glow discharge
during dep.

Processing

Physical Vapor Deposition (PVD)
Sputter Deposition



- Target material removed by kinetic energy of inert ions
- Requires plasma ignition for ionization of sputter gas (Ar)
- Minimum energy for ignition limits deposition rate ratio ~ 50:1 (2%)
- Good control over film properties (pressure, power, biasing, temperature)

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Reconstruction of a Can

Basic Understanding of
Processing-Structure-Prpoerties of Metals

*Courtesy of Novelis Corporation

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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

Reactive Films

http://www.indium.com/nanofoil/