Lecture # 2

8 September 2020

Slide-01

Outline of Lectures 2 and 3

Part 1:

Engineering Materials- Classification
Manufacturing Processes

Part 2:

A primer on microstructures
Microstructure-property interrelationships in metals

Part 3:

Casting/Solidification Processing,
Classification of casting processes

The Materials Selection Process

1. **Pick Application → Determine required Properties**

   Properties: mechanical, electrical, thermal, magnetic, optical, deteriorative.

2. **Properties → Identify candidate Material(s)**

   Material: structure, composition.

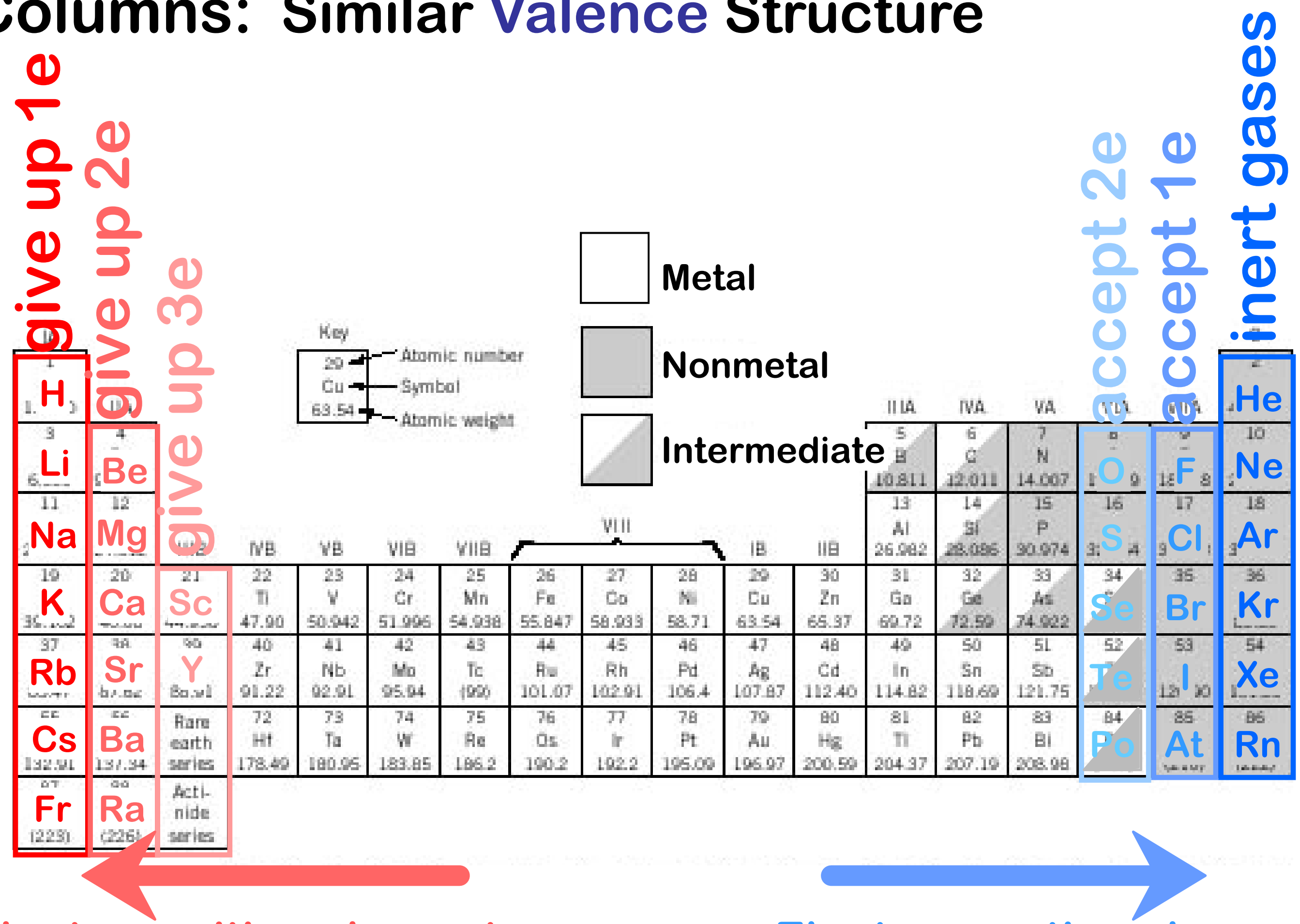
3. **Material → Identify required Processing**

   Processing: changes *structure* and overall *shape*
   ex: casting, sintering, vapor deposition, doping forming, joining, annealing.

- **Material Bonding and Structure**
- **Microstructure**

THE PERIODIC TABLE

- **Columns: Similar Valence Structure**

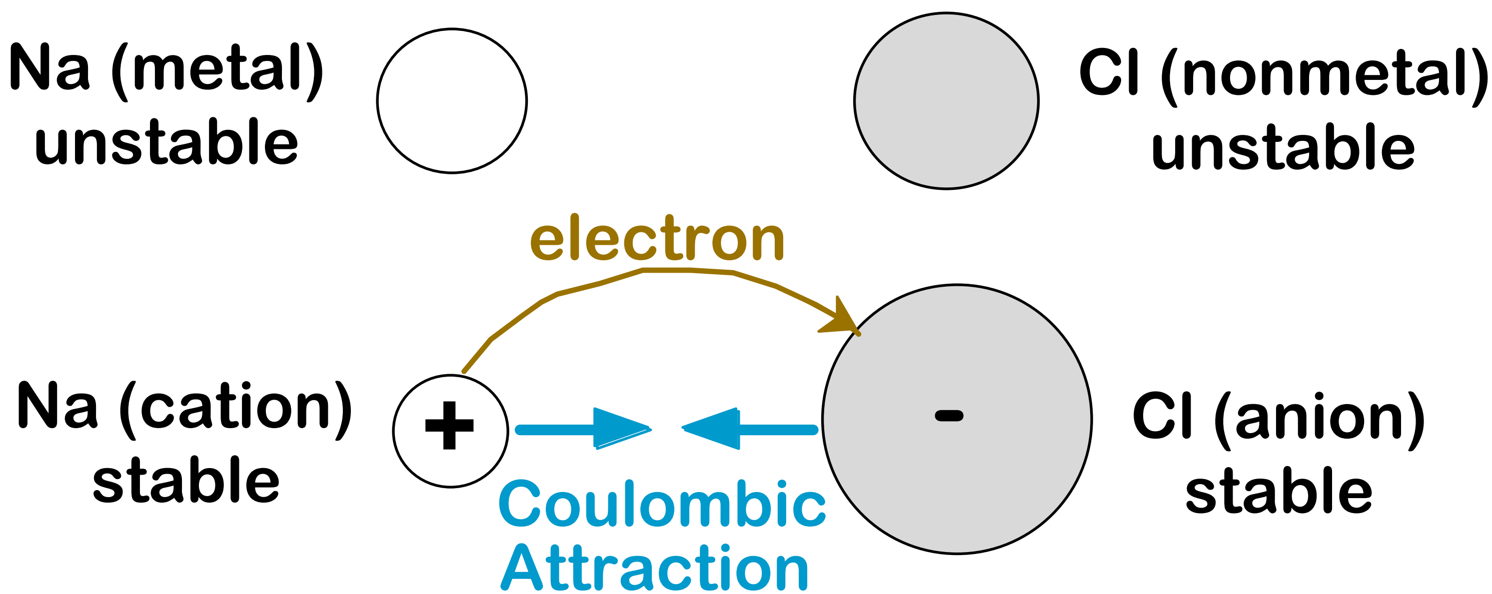


Electropositive elements: Readily give up electrons to become + ions.

Electronegative elements: Readily acquire electrons to become - ions.

IONIC BONDING

- Occurs between + and - ions.
- Requires **electron transfer**.
- Large difference in electronegativity required.
- Example: NaCl



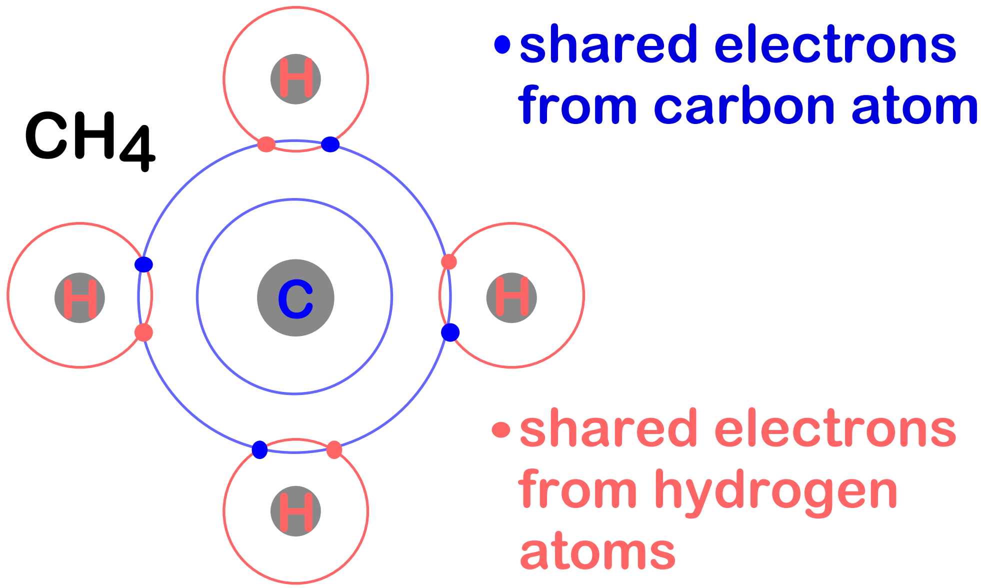
COVALENT BONDING

- Requires **shared electrons**
- Example: CH_4

C: has 4 valence e,
needs 4 more

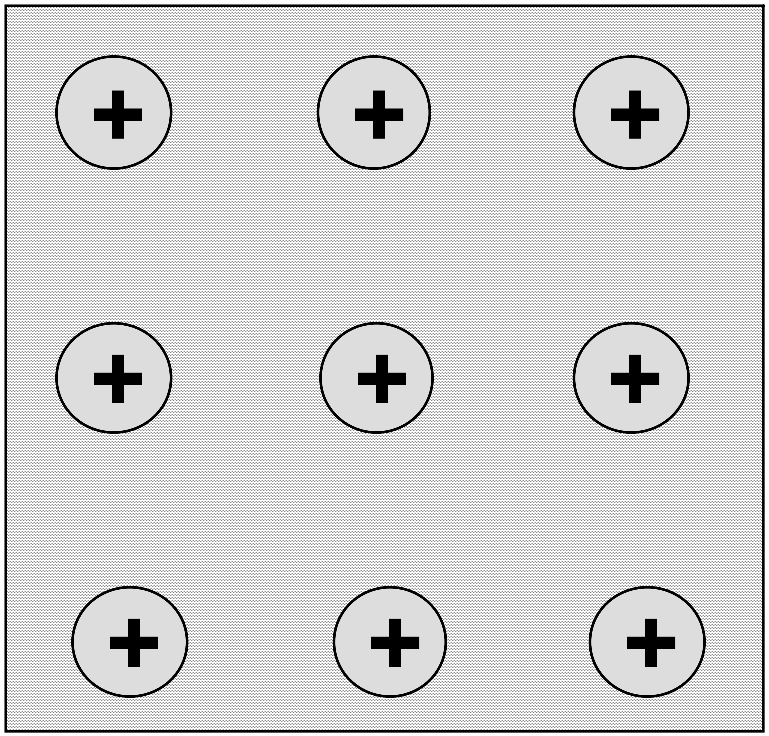
H: has 1 valence e,
needs 1 more

Electronegativities
are comparable.



METALLIC BONDING

- Arises from a sea of **donated valence electrons** (1, 2, or 3 from each atom).

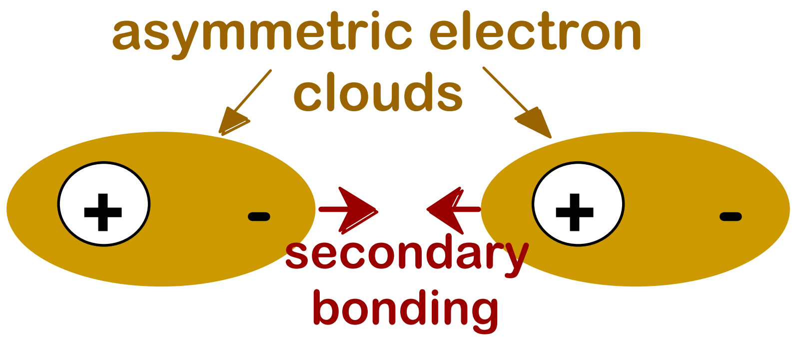


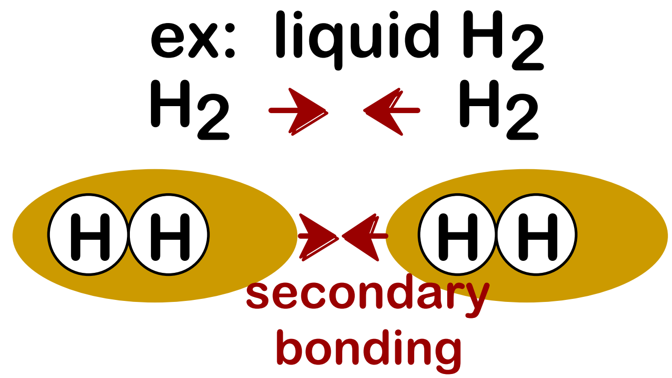
- Primary bond for metals and their alloys

SECONDARY BONDING

Arises from interaction between dipoles

- **Fluctuating dipoles**



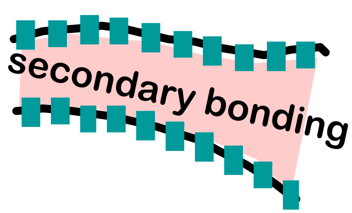


- **Permanent dipoles-molecule induced**

-general case:

-ex: liquid HCl

-ex: polymer



BONDING IN MATERIALS

Ceramics

(Ionic & covalent bonding):

Large bond energy

large T_m

large E

small α

Metals

(Metallic bonding):

Variable bond energy

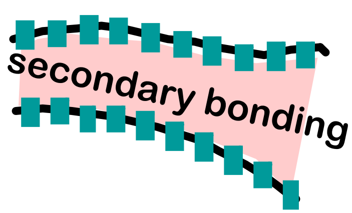
moderate T_m

moderate E

moderate α

Polymers

(Covalent & Secondary):



Directional Properties

Secondary bonding dominates

small T

small E

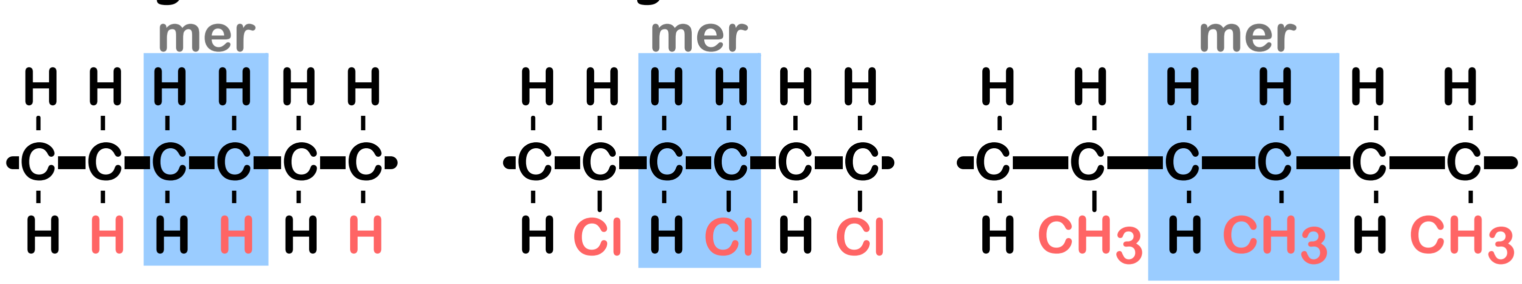
large α

SUMMARY: BONDING

Type	Bond Energy	Comments
Ionic	Large!	Nondirectional (ceramics)
Covalent	Variable large-Diamond small-Bismuth	Directional semiconductors, ceramics polymer chains
Metallic	Variable large-Tungsten small-Mercury	Nondirectional (metals)
Secondary	smallest	Directional inter-chain (polymer) inter-molecular

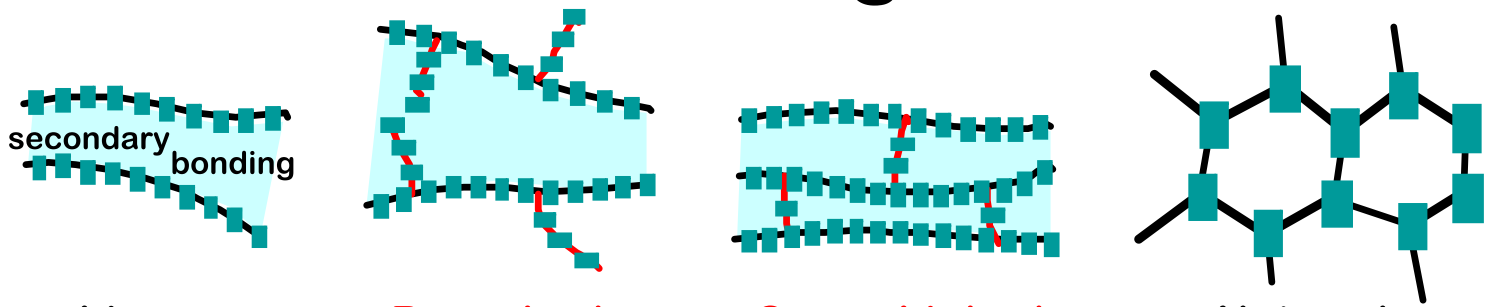
POLYMER STRUCTURE

- **Polymer = many mers**



Polyethylene (PE) Polyvinyl chloride (PVC) Polypropylene (PP)

- **Covalent chain configurations and strengt**



Linear **Branched** **Cross-Linked** **Network**

Direction of increasing strength

METALLIC STRUCTURE

- **tend to be densely packed.**
- **have several reasons for dense packing:**

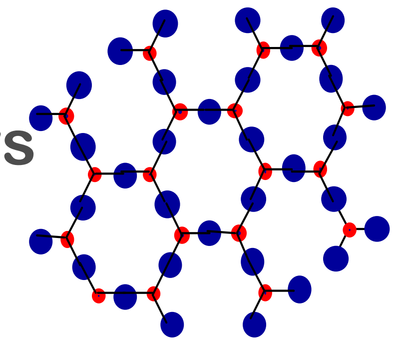
  -Typically, only one element is present, so all atomic radii are the same.
  -Metallic bonding is not directional.
  -Nearest neighbor distances tend to be small in order to lower bond energy.

- **have the simplest crystal structures.**

Crystal Structure & Microstructure

Crystalline materials...

- atoms pack in periodic, 3D arrays
- typical of: -metals
  -many ceramics
  -some polymers

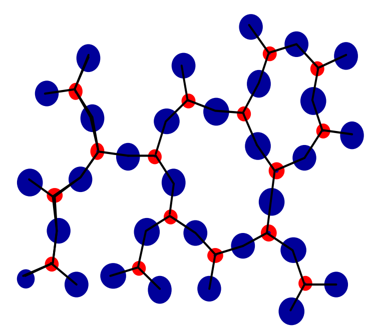


crystalline SiO_2

• Si ● Oxygen

Noncrystalline materials...

- atoms have no periodic packing
- occurs for: -complex structures
  -rapid cooling



noncrystalline SiO_2

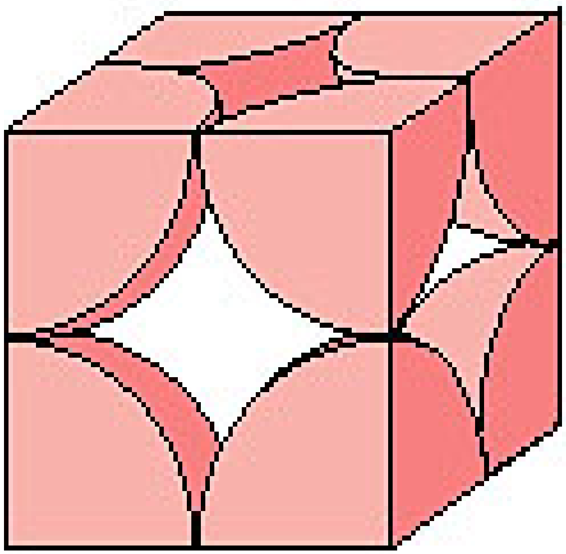
"Amorphous" = Noncrystalline

How do metals freeze?

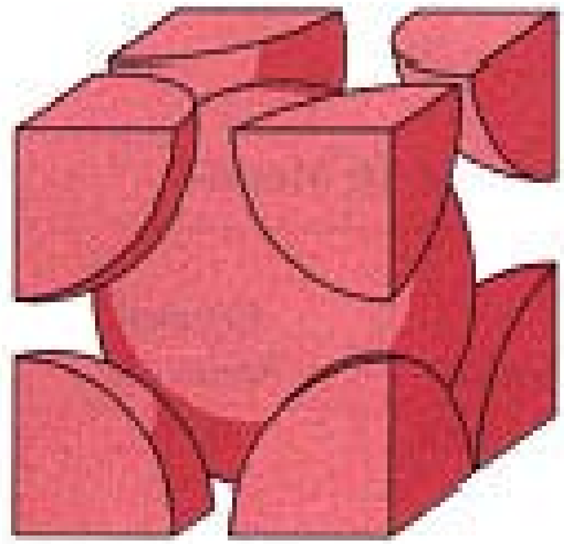
Metals freeze in much the same way that water freezes into the familiar snowflakes.

The Rasmussen & Libbrecht Collection

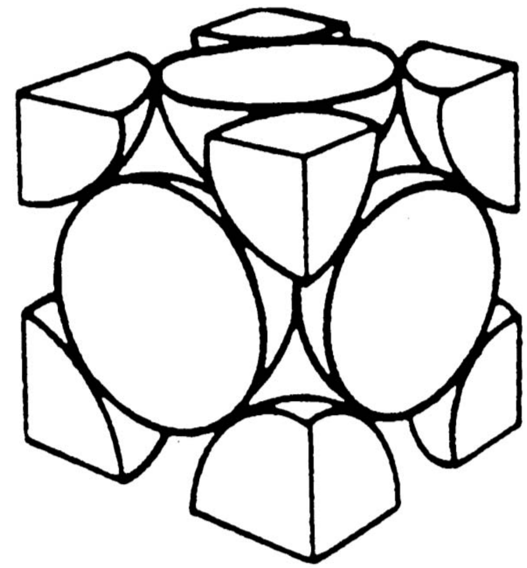
Simple Cubic Structure



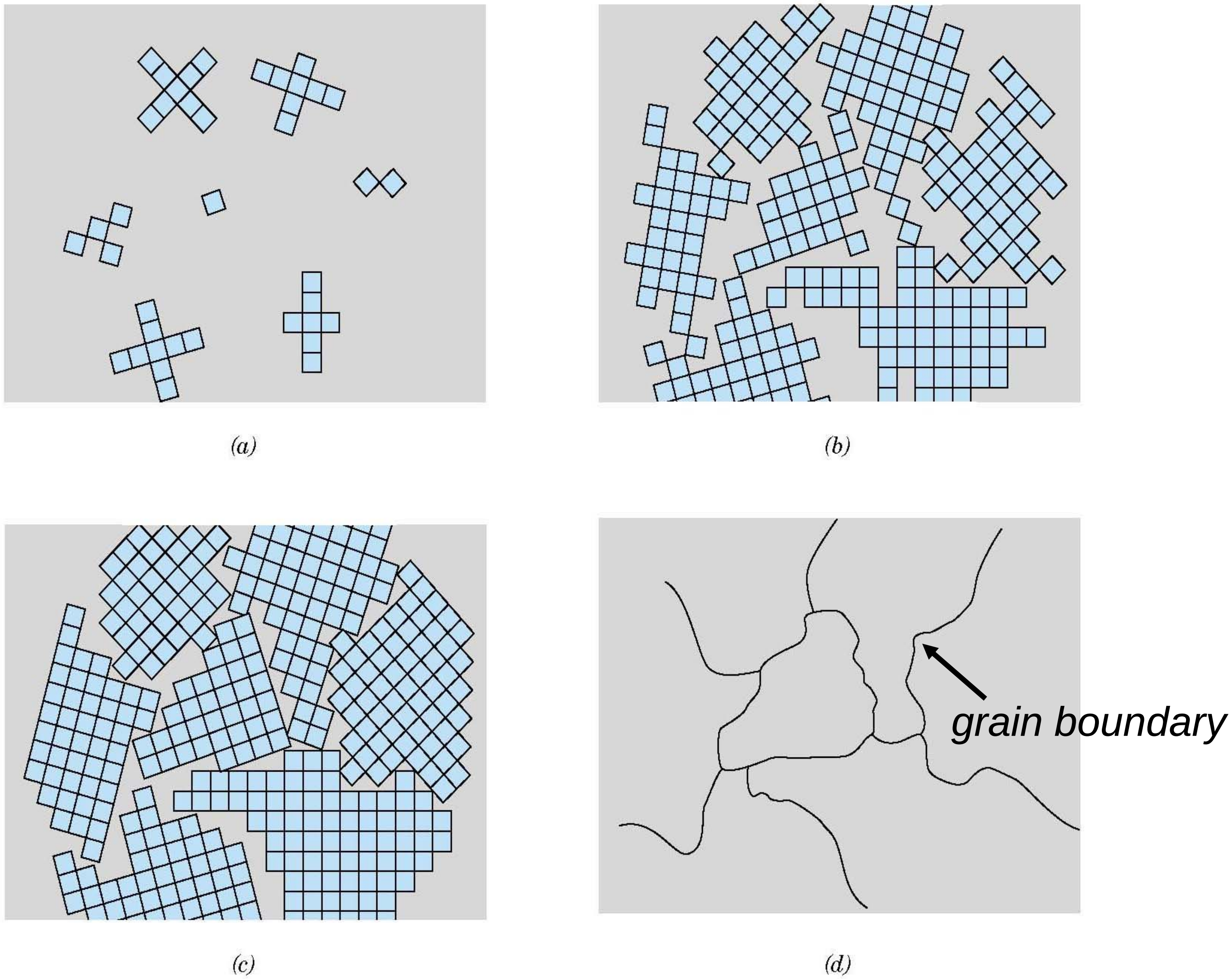
Body-Centered Cubic



Face-Centered Cubic



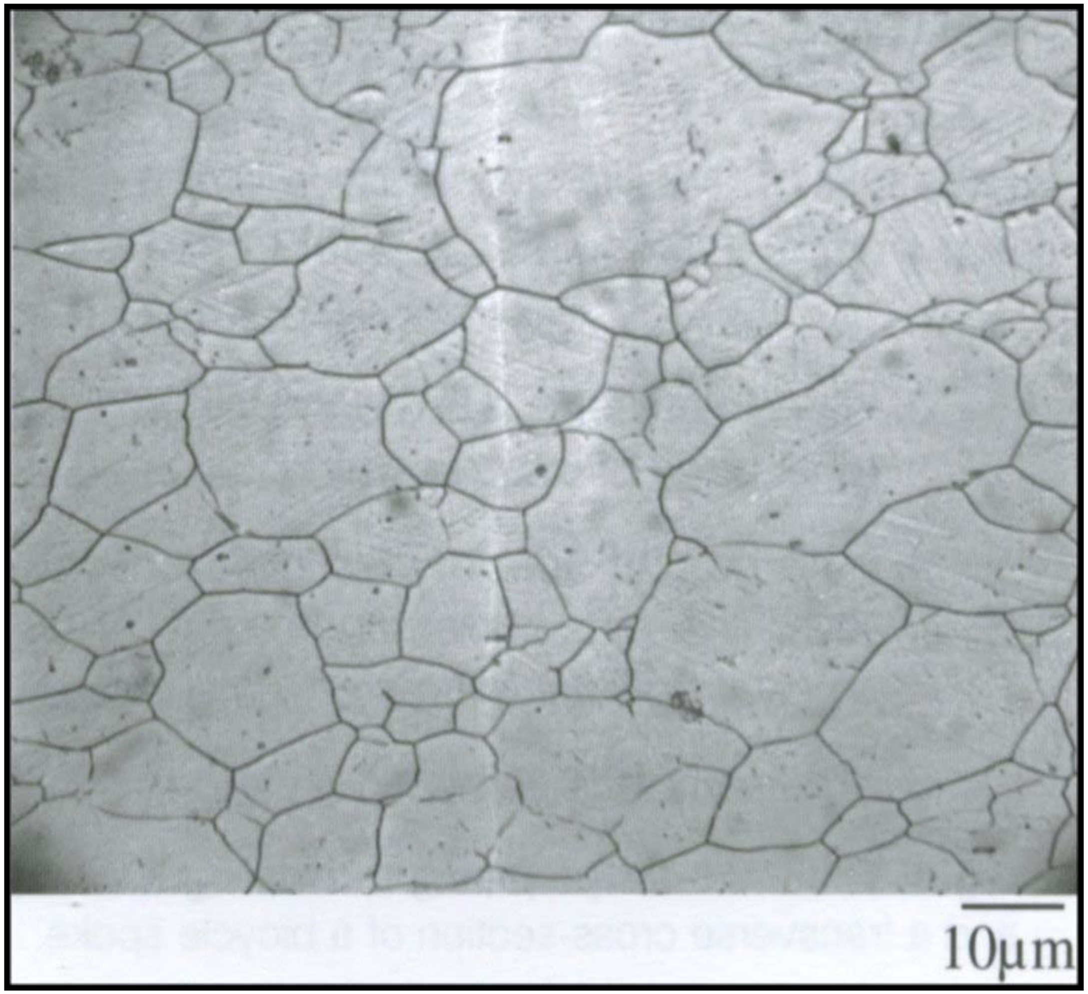
Various Stages during Solidification of a Crystalline Material



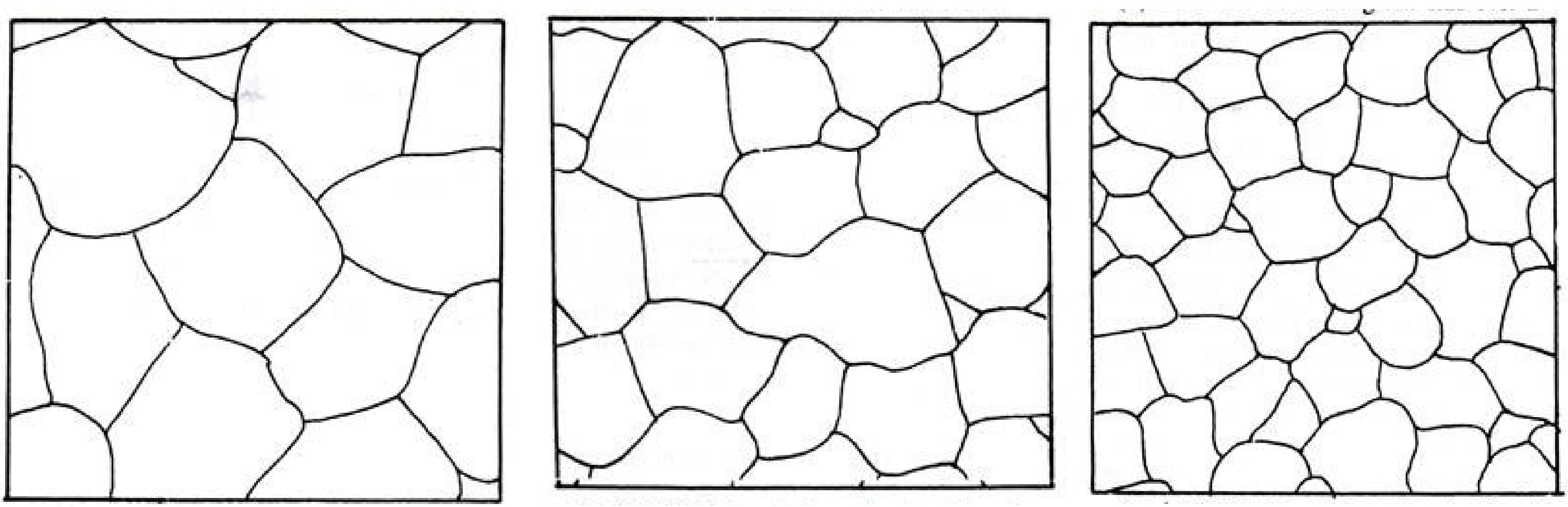
(a) Small crystallite nuclei; (b) growth of crystallites;
(c) solidification complete; (d) grain structure as it appears under a microscope

A 2D analog of a polycrystal, made of bubbles, showing the varying degree of atomic disorder

Microstructure of Stainless Steel



Equiaxed Microstructures with Varying Grain Sizes

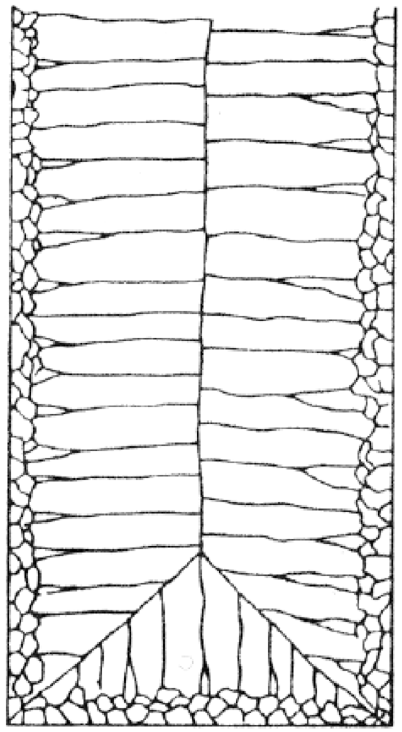


Questions:

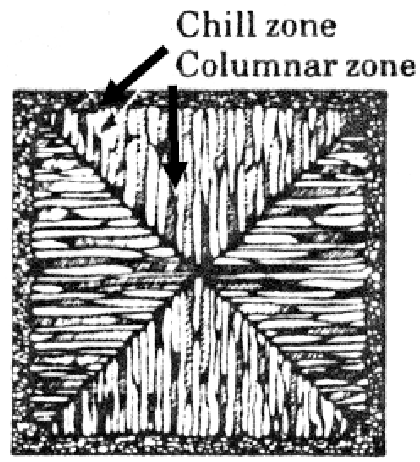
1. What is the effect of grain size on the strength of materials at room temperature?
2. What is Creep and what is the influence of the grain size on creep strength of materials?

Columnar Microstructure

Vertical Section

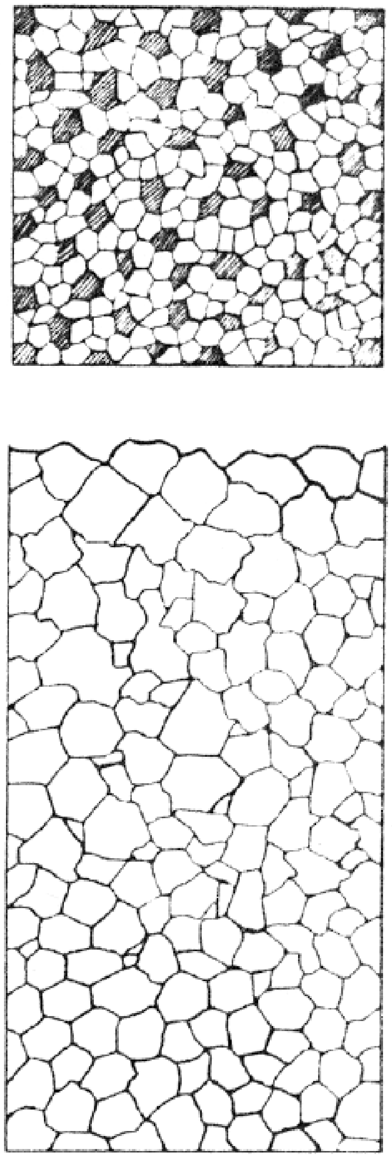


Horizontal Section



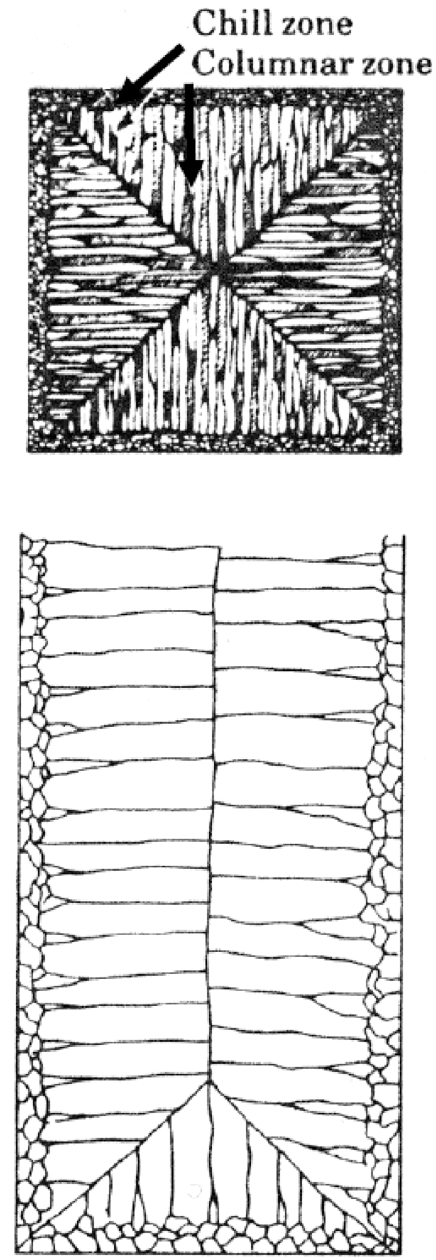
Equiaxed *versus* Columnar Microstructure

Equiaxed
structure

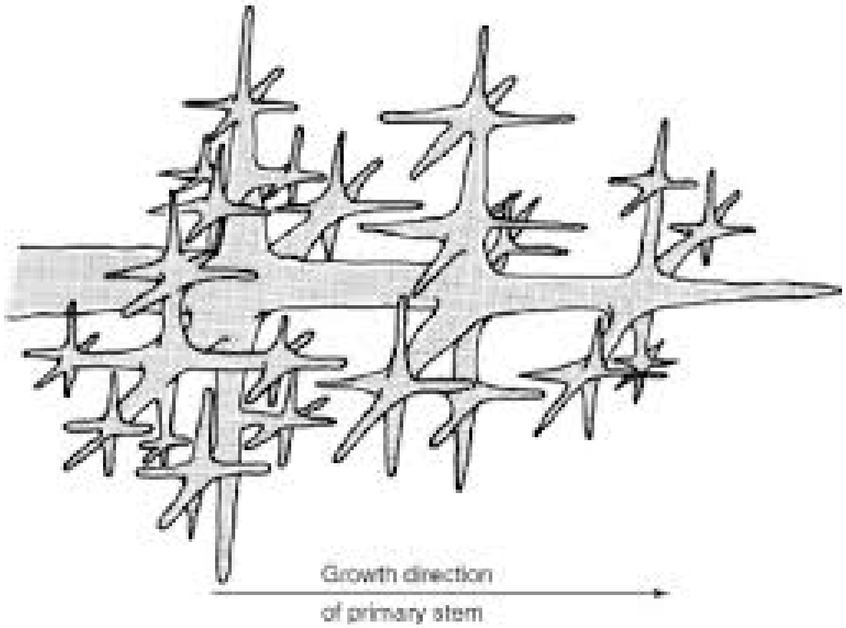


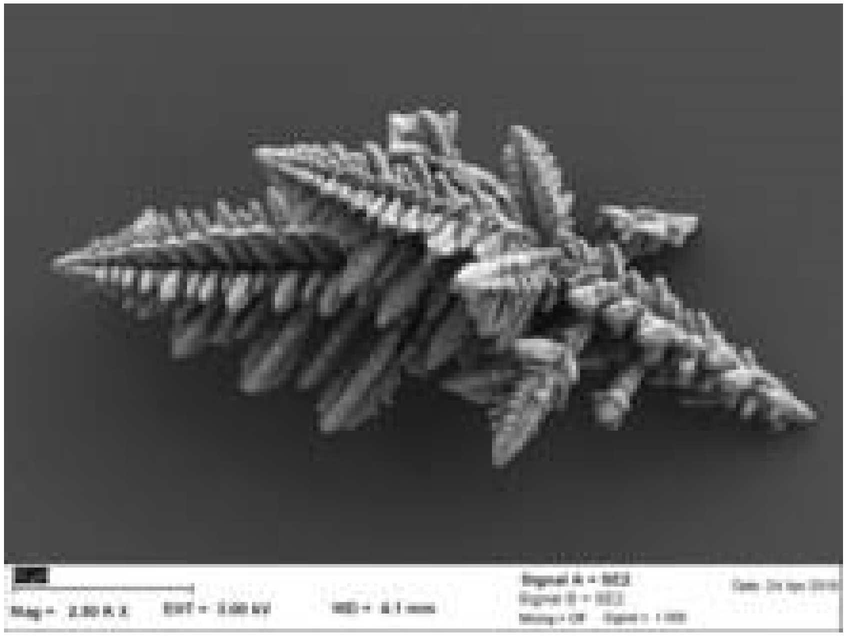
Horizontal
Section

Vertical
Section

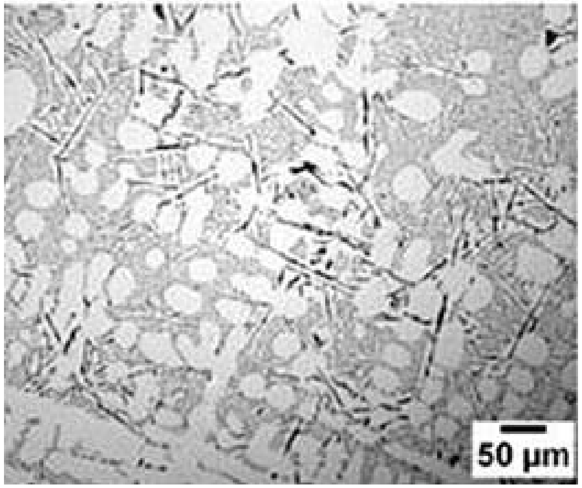


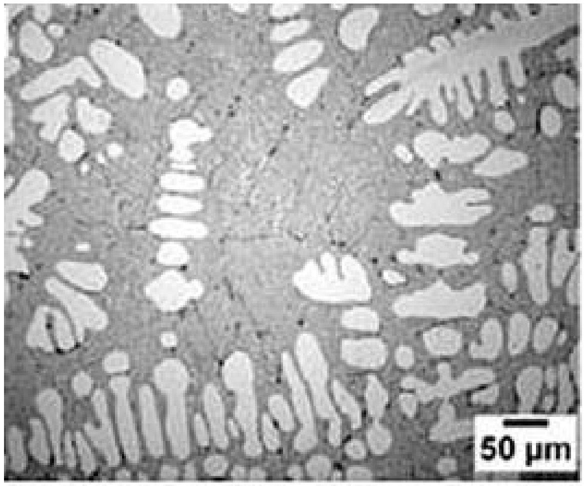
Dendritic Microstructure





Dendrites in Aluminum Alloy





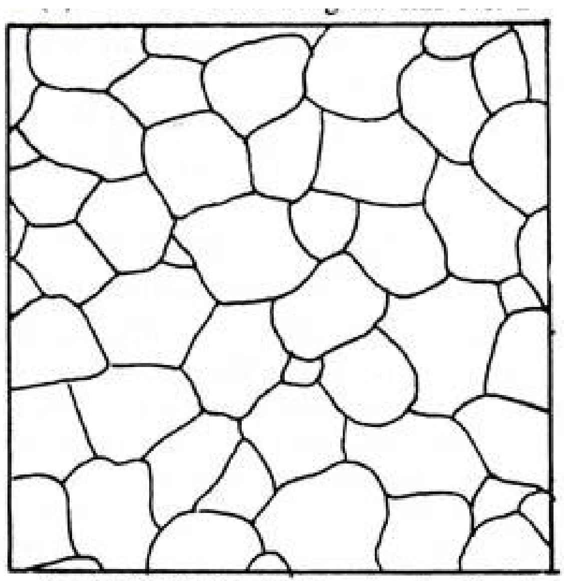
Effect of Processing Parameters on Microstructure

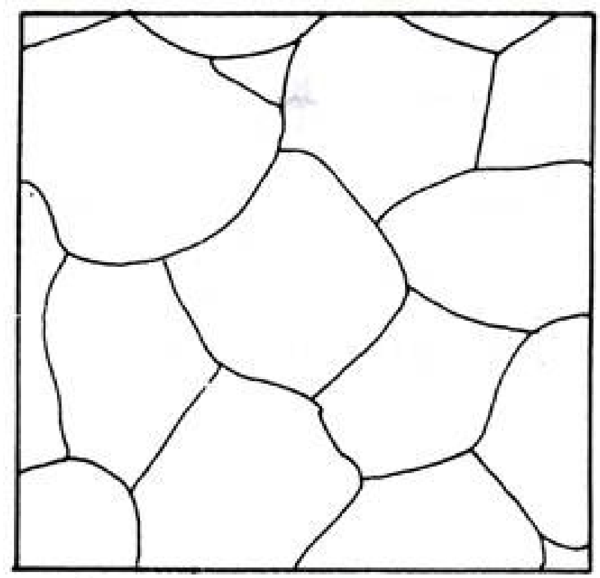
Mixed Microstructures

- Nb-Hf-W plate with an electron beam weld.
- Each "grain" is a single crystal.

Callister 6e

Effect of Temperature and Time



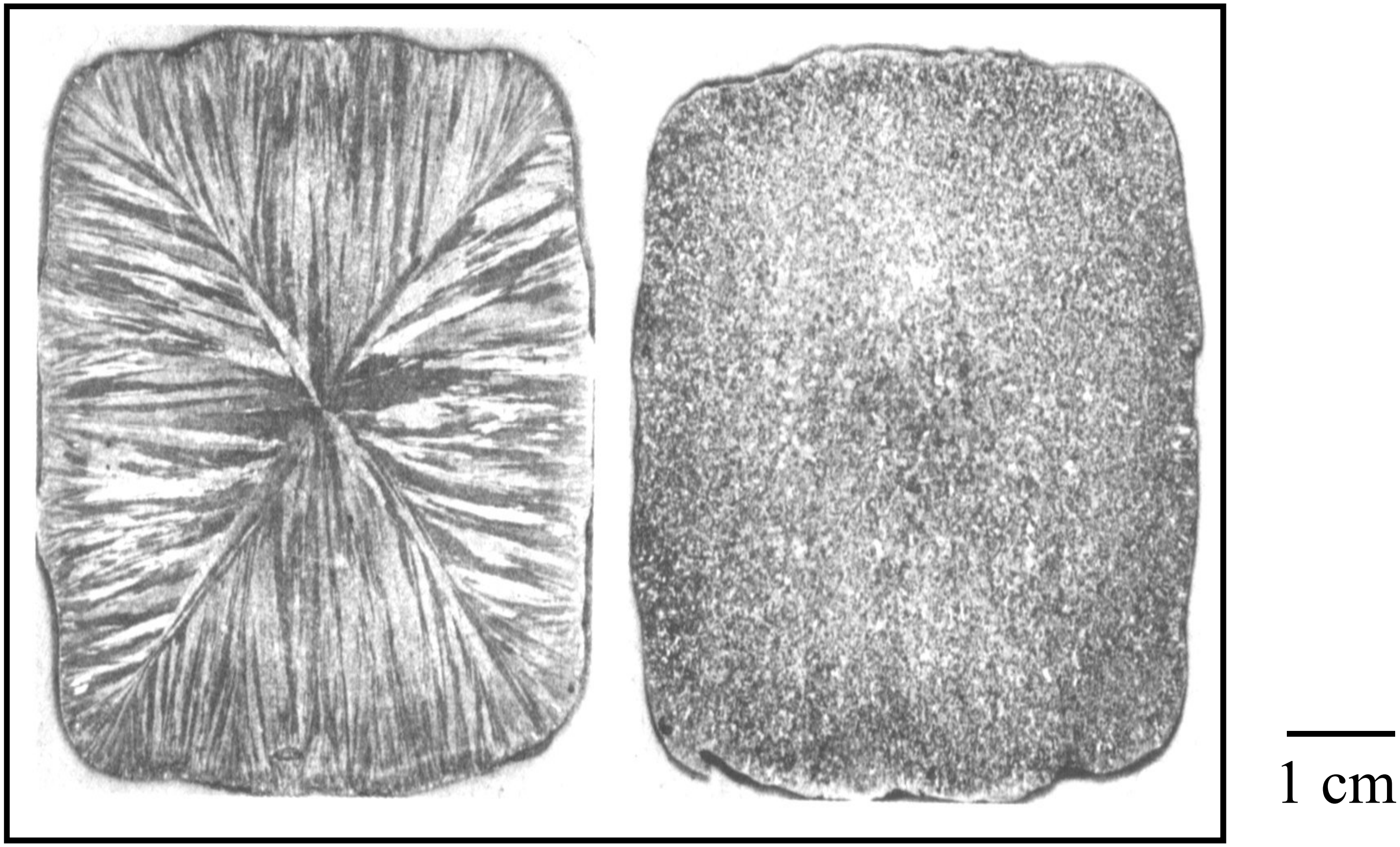


Microstructure to the right is coarser than the one in the left. Prolonged hearting at the same temperature or subjecting the material to an elevated temperature (keeping the time same) results in microstructural coarsening

Effect of Cooling Rate on Microstructure

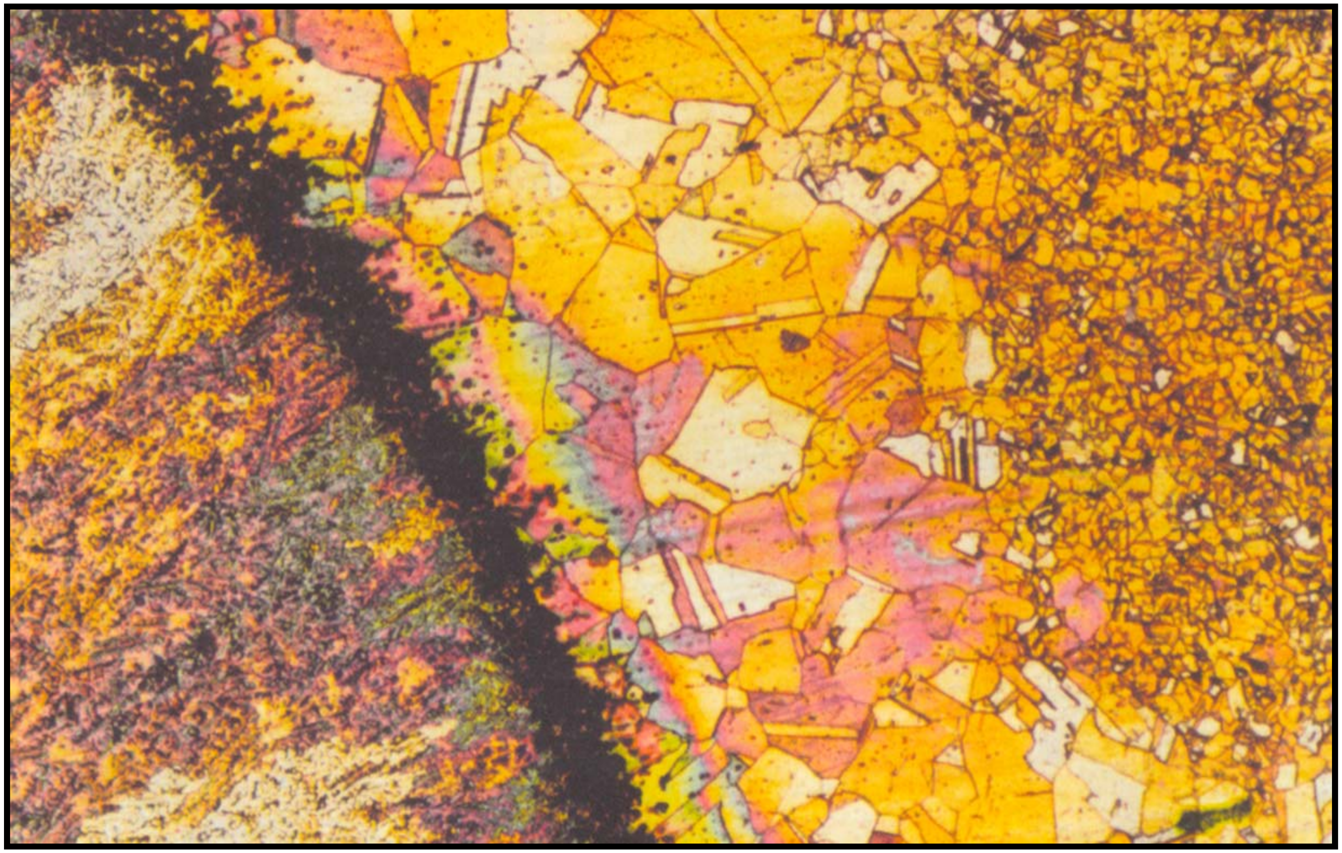
Illustration: Cast Structure in Aluminum

***- Effect of mould materials** (cooling rate)*



- **Cast in Sand Mould**
- **Cast in water-cooledCu mould**

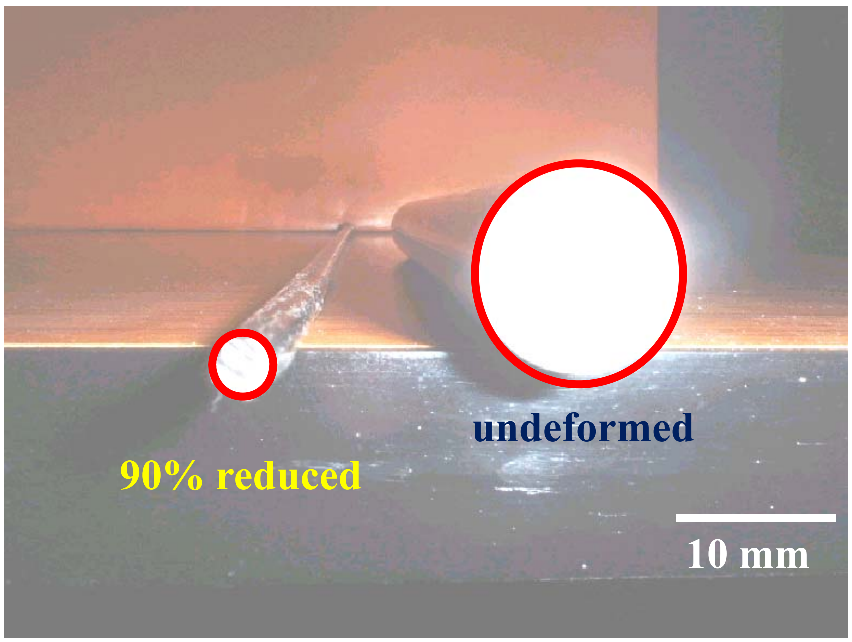
Weld Zone Structure of Stainless Steel
-Effect of Heating

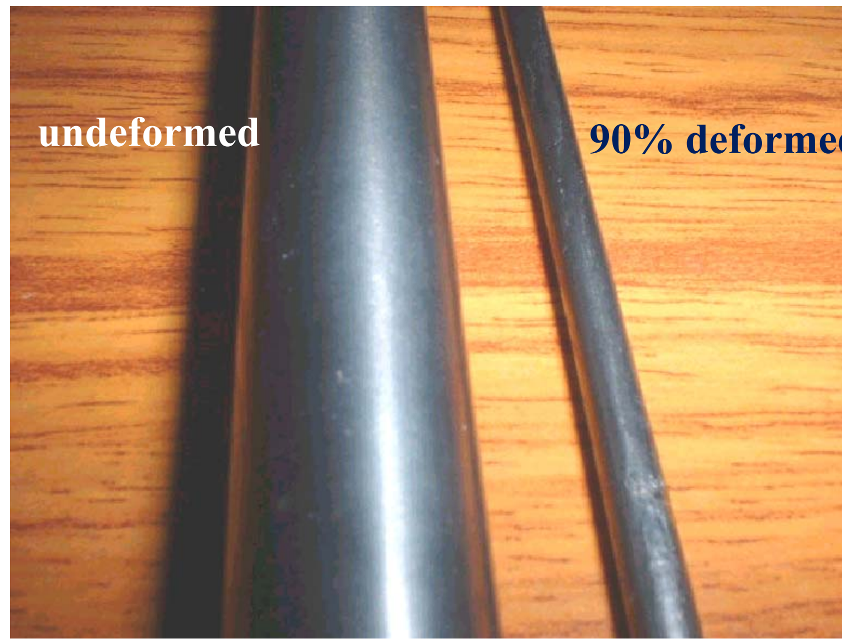


Optical micrograph of a butt weld joint in a stainless steel (grade SS321) showing weldment, fusion zone, heat-affected zone, and parent metal. The picture shows marked grain growth at the HAZ which can lead to failure in the welded structure. This picture was awarded the Ist prizein the Optical Microscopy category during the metallography contest held during NMD-ATM2004.

Source: IIM Metal News, v. 8, n. 4, Aug 2005

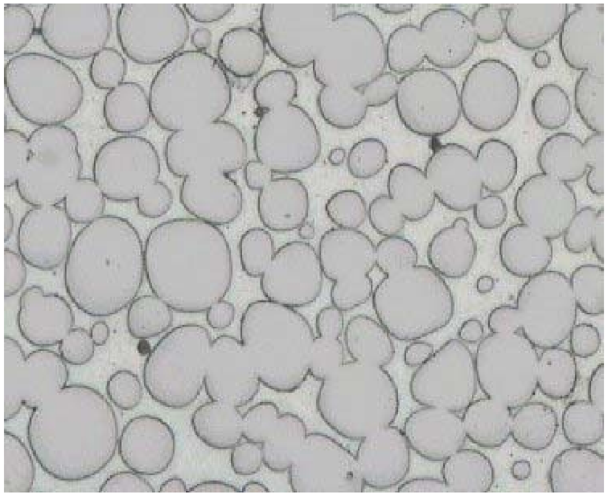
Effect of Deformation (by swaging) on the <u>Shape</u> of Tungsten Alloy



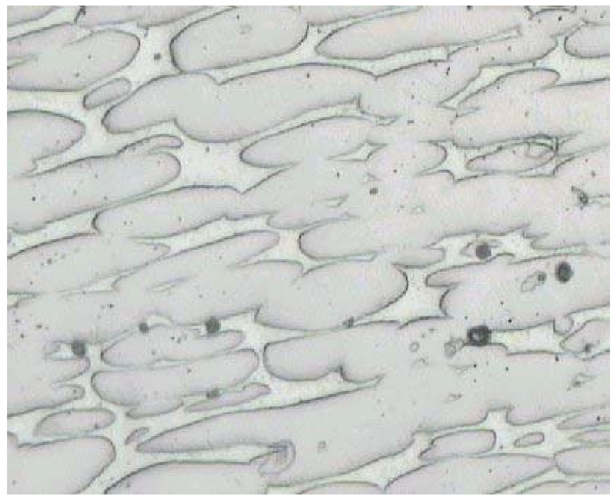


composition, wt.%: 90W-7Ni-3Fe Alloy

Effect of Deformation (by swaging) on the <u>Microstructure</u> of Tungsten Alloy



Undeformed



70% swaged

20 µm

90% swaged