

재료상변태

Phase Transformation of Materials

2008.09.02.

박은수

서울대학교 재료공학부

Materials Science and Engineering

합금설계 + 공정(工程)

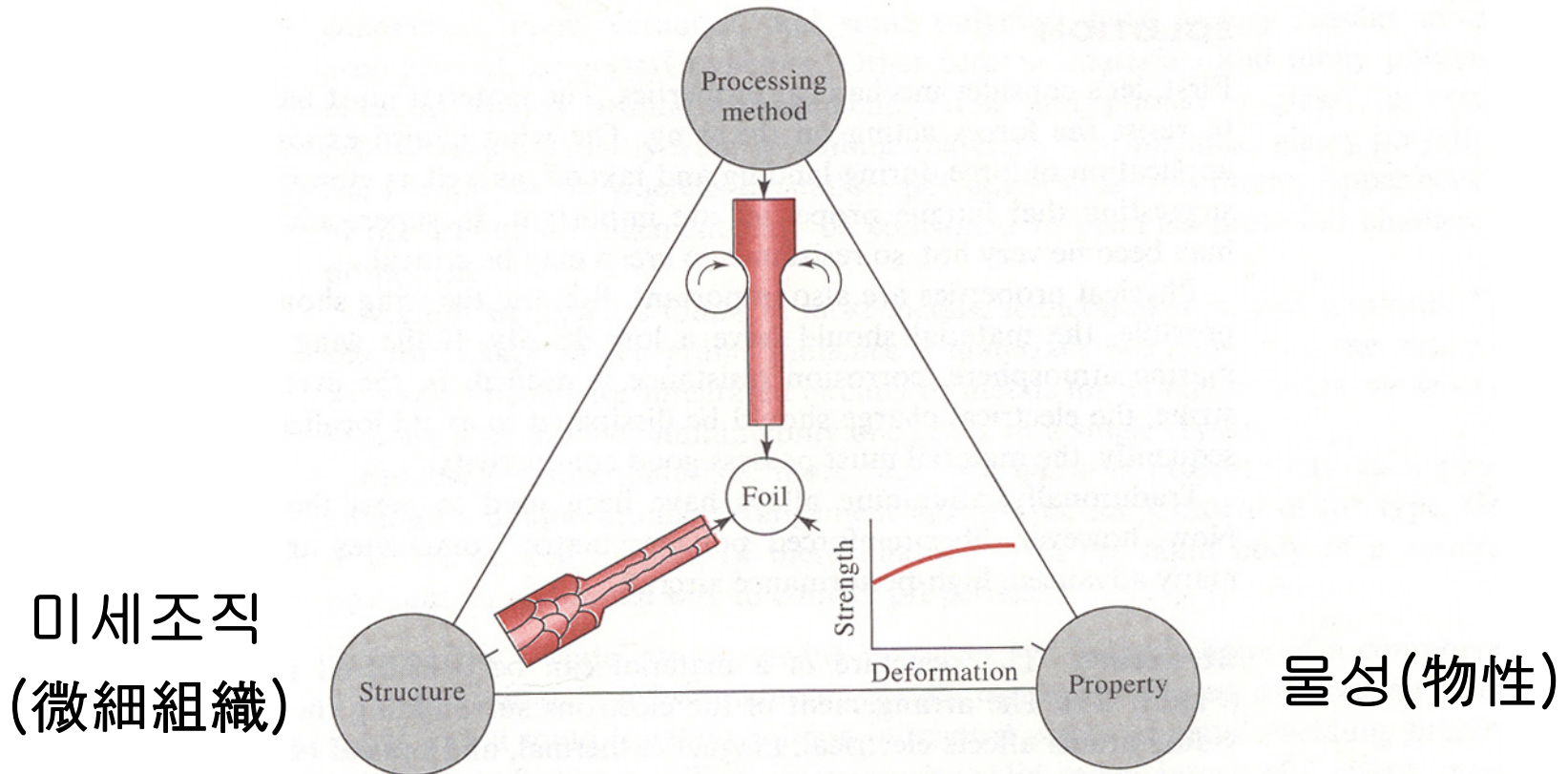
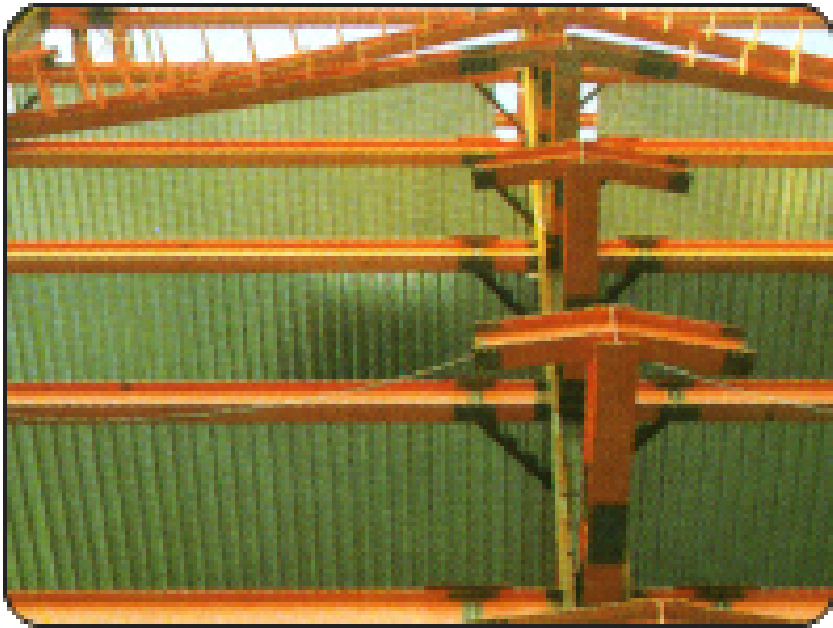


FIGURE I-8 The three-part relationship between structure, properties, and processing method. When aluminum is rolled into foil, the rolling process changes the metal's structure and increases its strength.

One of the Most Popular Structural Materials ; Iron-Carbon Alloy (or Steel)



Steel frame of building



Steel house

Application of Iron-Carbon Alloy

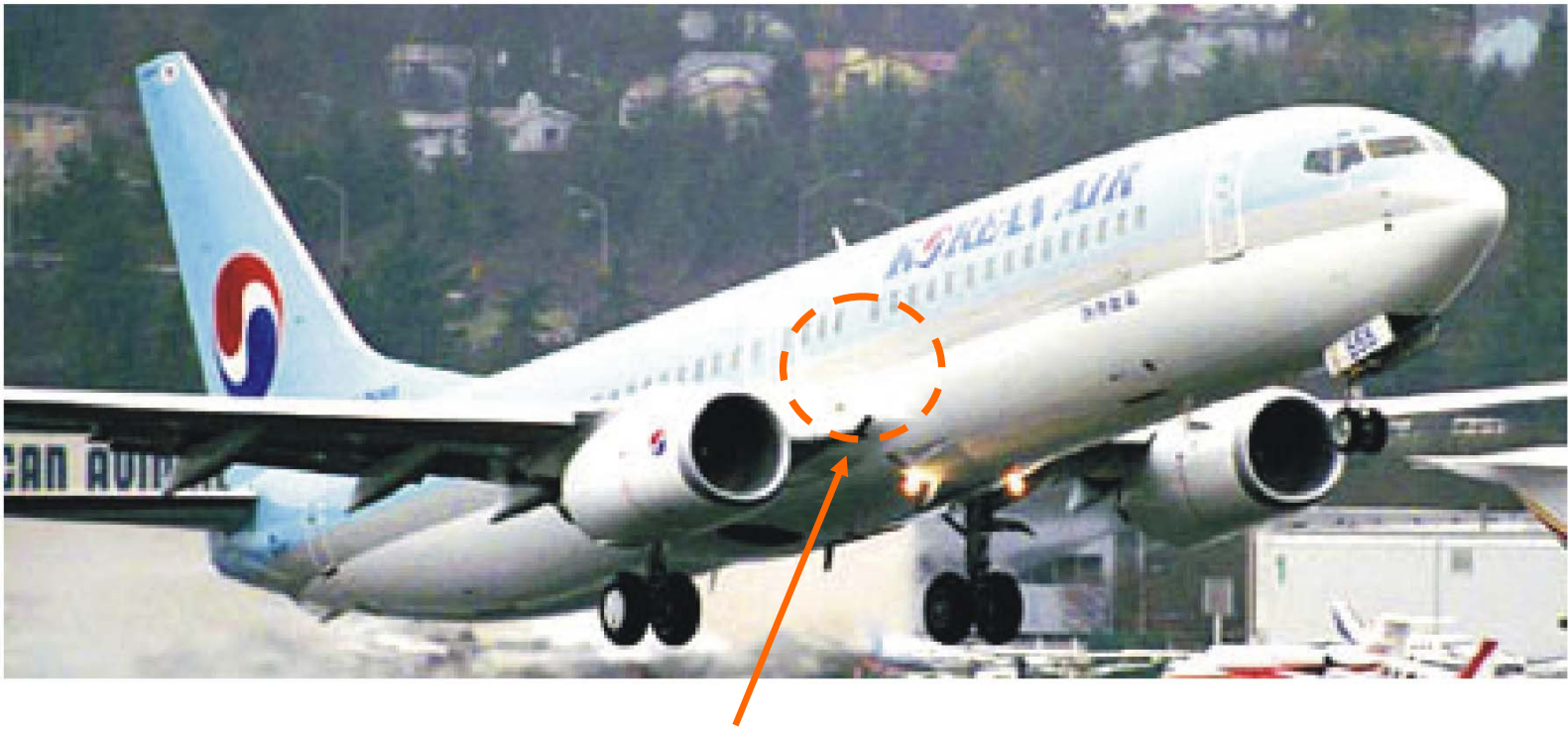
K1 – main battle tank of Korea army



Need of the strongest materials

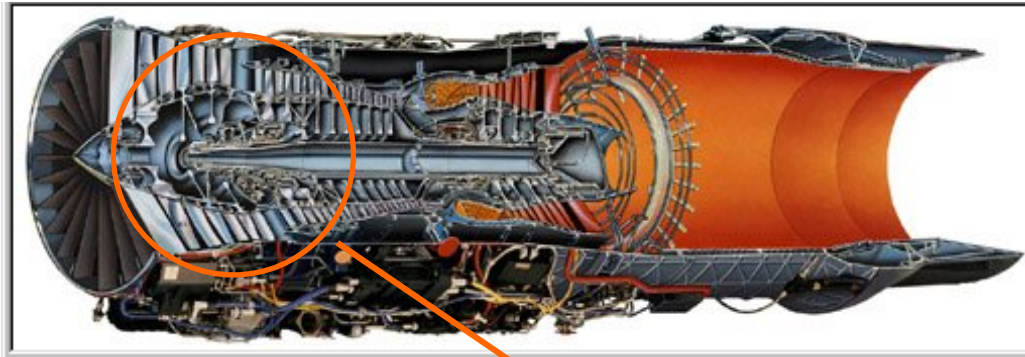
Dominant Material for Airplanes ; Aluminum Alloy

B737-800 of Korean Air



Need of light, strong and tough material

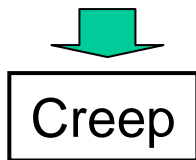
A Example of Grain Boundary Engineering ; Turbine blade in Aircraft Engine



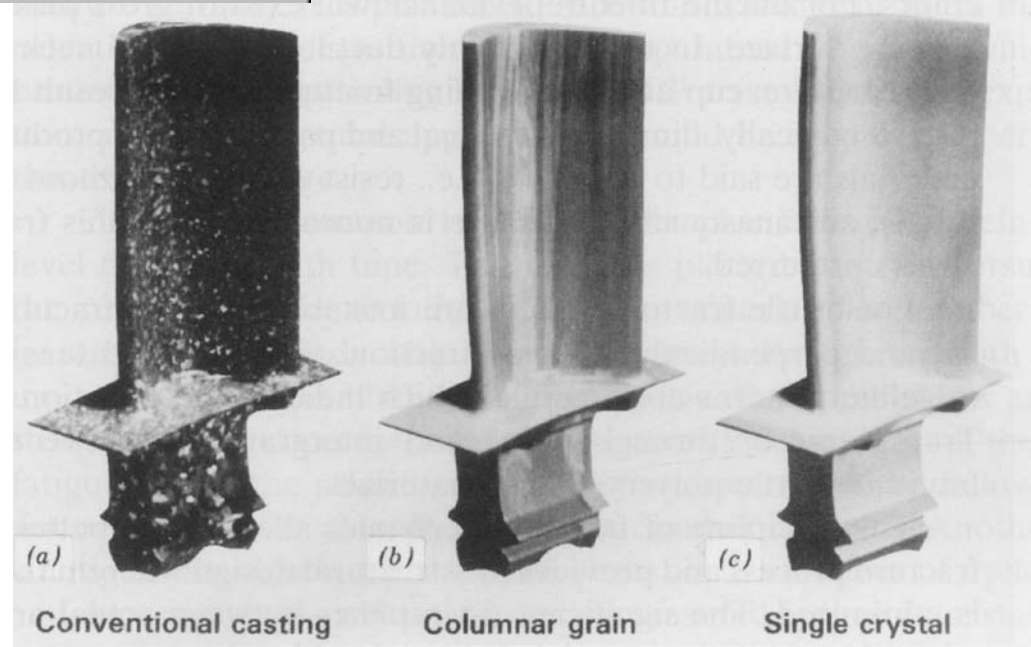
F100-PW-229
in F-16 fighting falcon

Turbine Blade

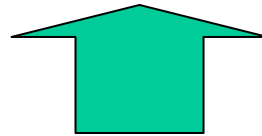
Grain boundaries
at high Temperature ;
Diffusion path of atoms



Reducing grain boundaries



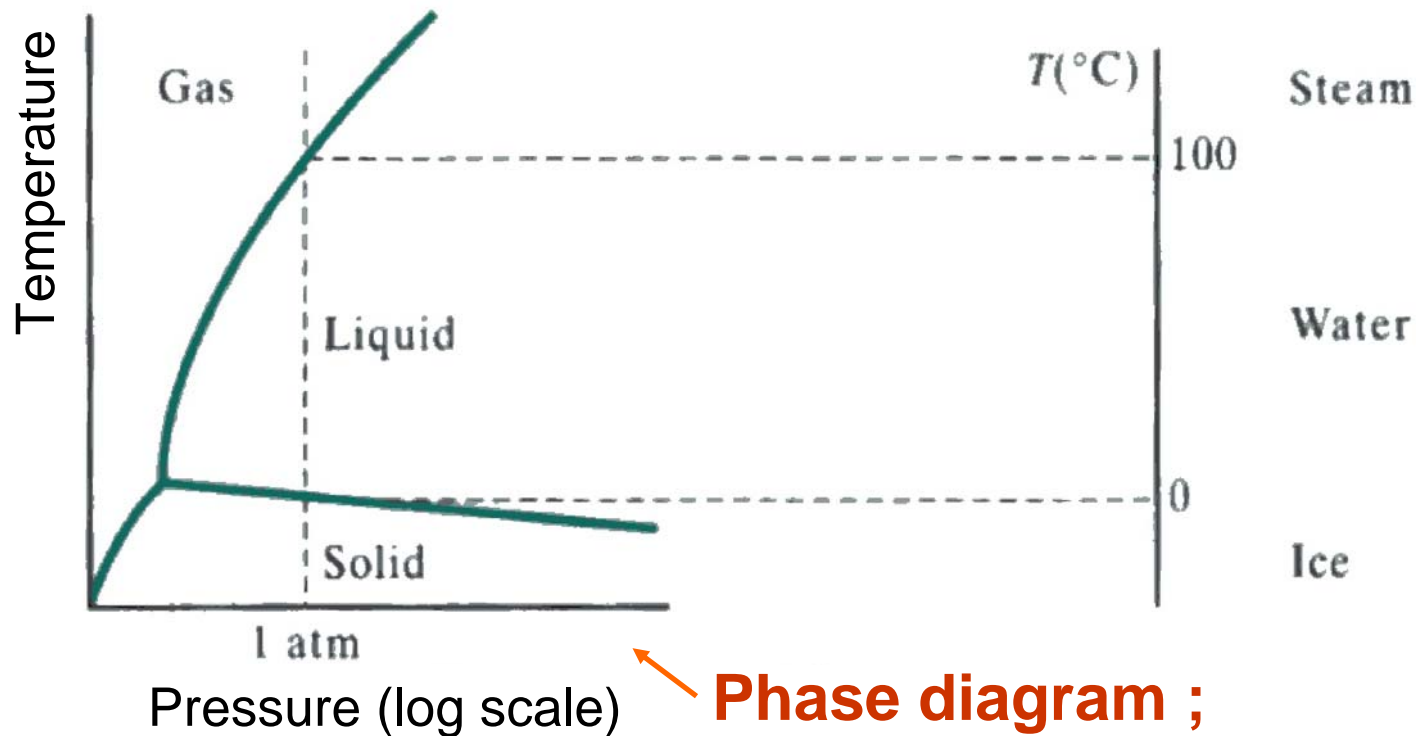
Better Material Properties



**Microstructure Control
of Materials**

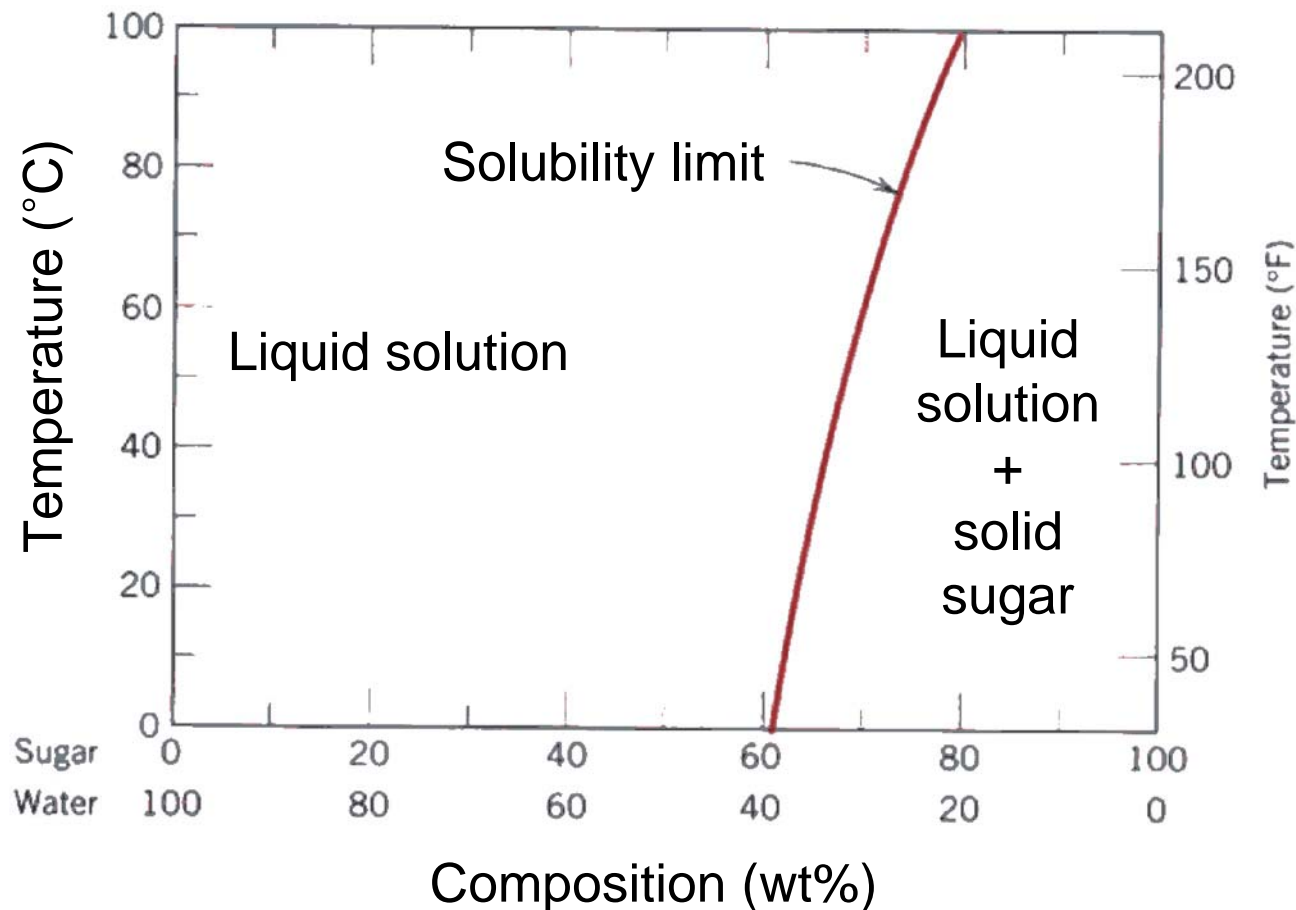
What is Phase?

A phase is a chemically and structurally homogeneous portion of the microstructure.

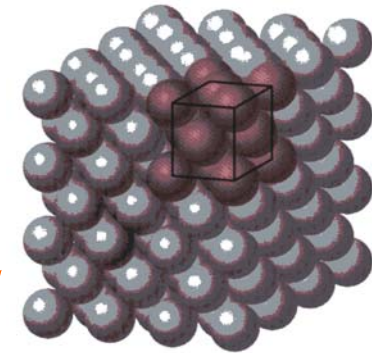
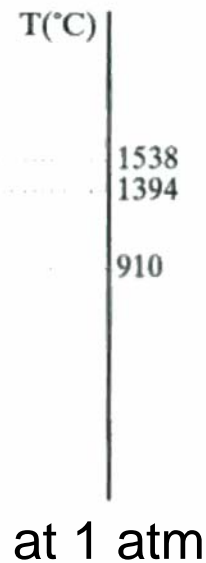
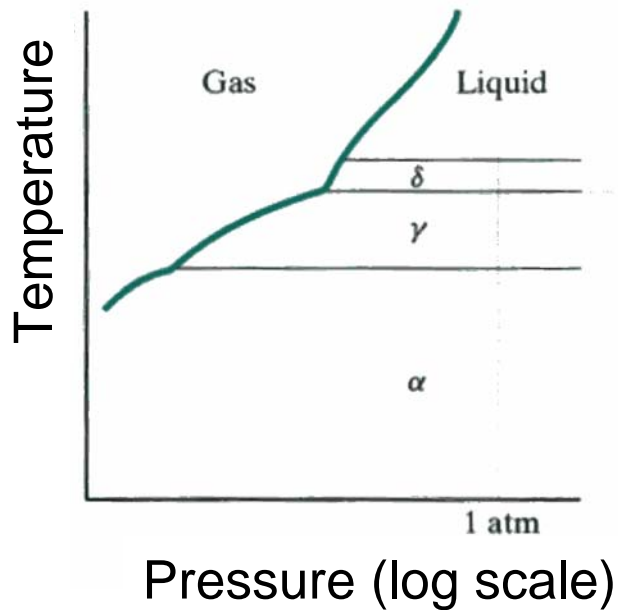


**Phase diagram ;
equilibrium phase of material**

Phase Diagram of Temperature – Composition ; More useful in materials science & engineering

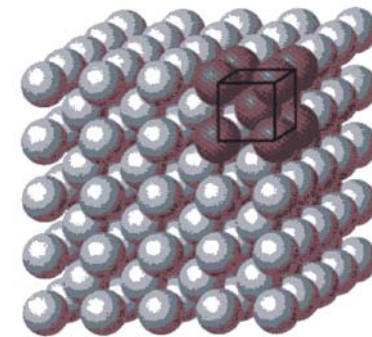


Phase Transformation of Iron and Atomic Migration



Face-Centered Cubic

Atomic Migration

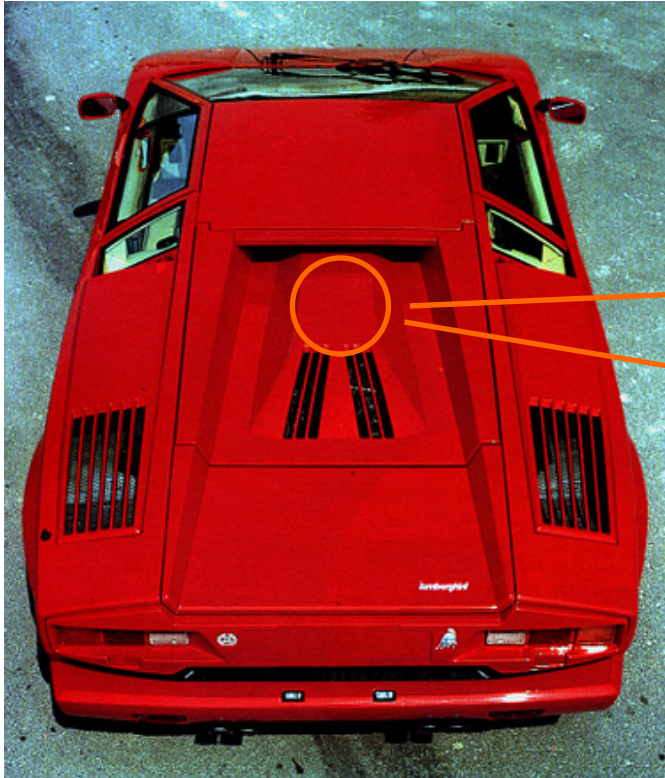
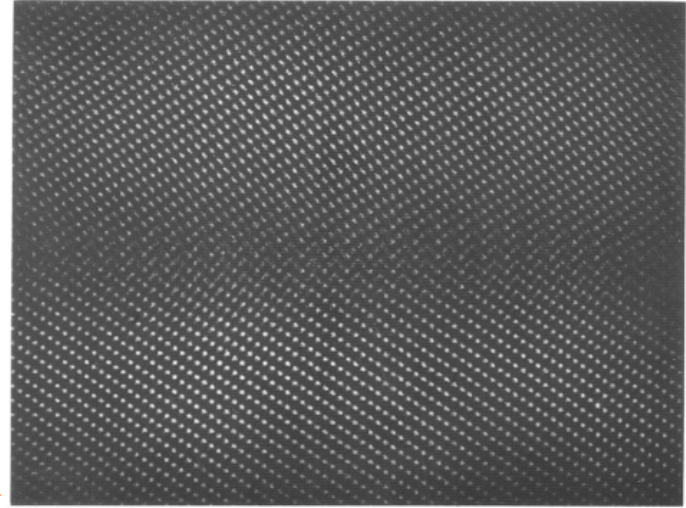


Body-Centered Cubic

What is Microstructure in Materials Science ?

**Materials ;
Assemblage of Atoms**

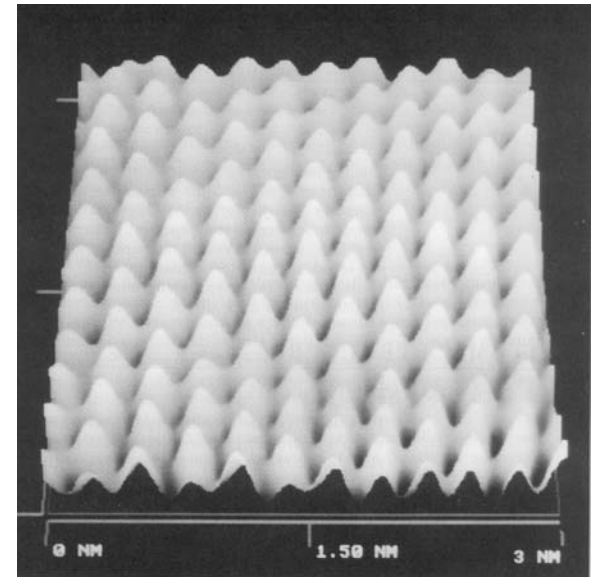
**Transmission Electron
Microscope**



Lamborghini - Countach



**Atomic Force
Microscope**



Perfect Crystal is good in many aspects, But ...

❑ Imperfection in Metallic Materials ;

Point defect : Vacancies,
Impurity atoms

Line defect : Dislocations

Plane defect : Grain Boundaries,
Free Surfaces

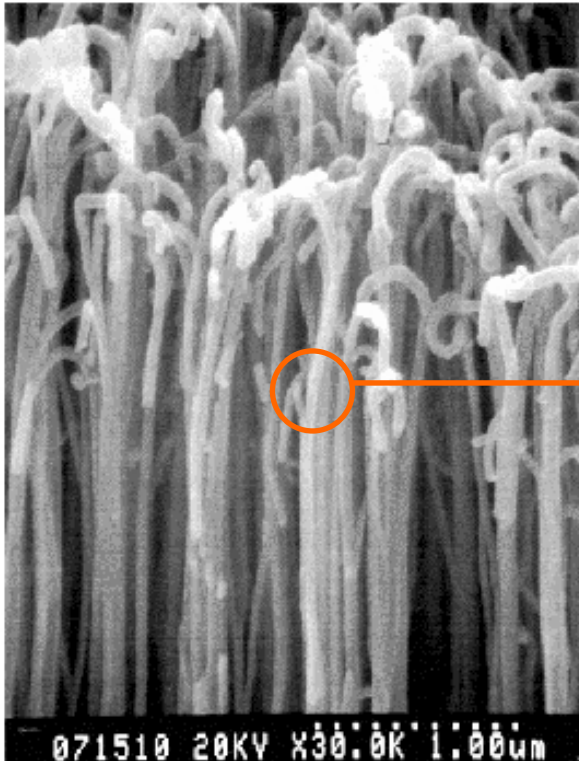
Bulk defect : Voids, Cracks

❑ Second Phase Particles in Matrix

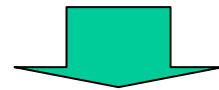
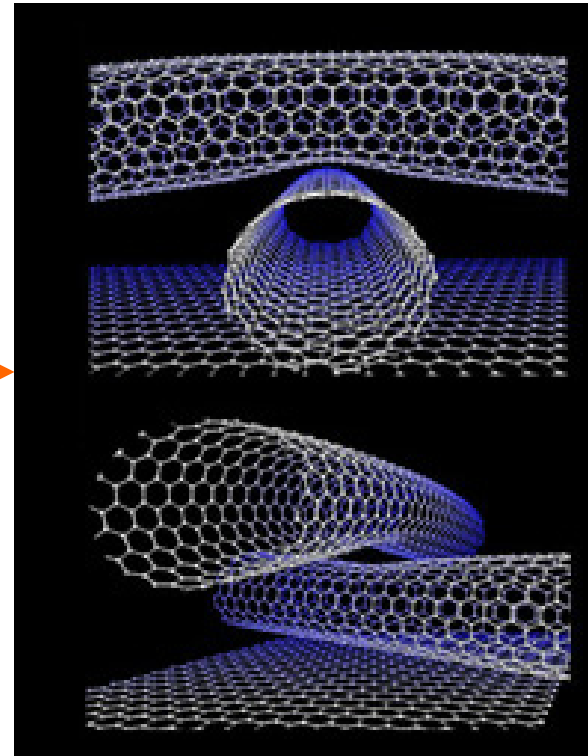


**Mechanical Properties ;
Magnetic properties
Electrical properties
Etc.**

Perfect Crystals without Defect



Carbon
Nanotubes



High strength, unique magnetic/electrical properties

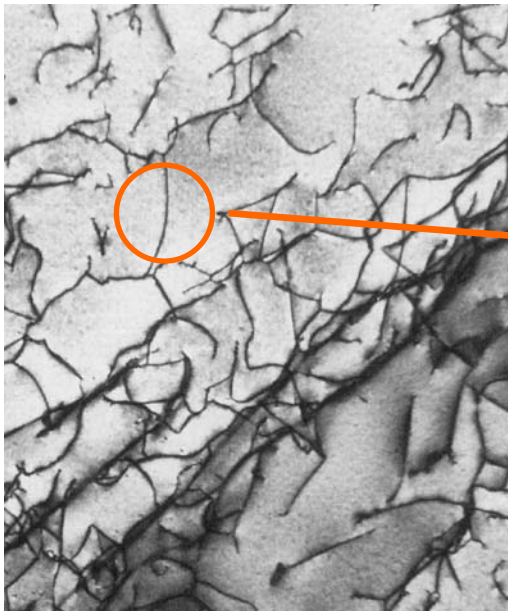
Dislocations



**SR-71
with armor of
titanium alloy**

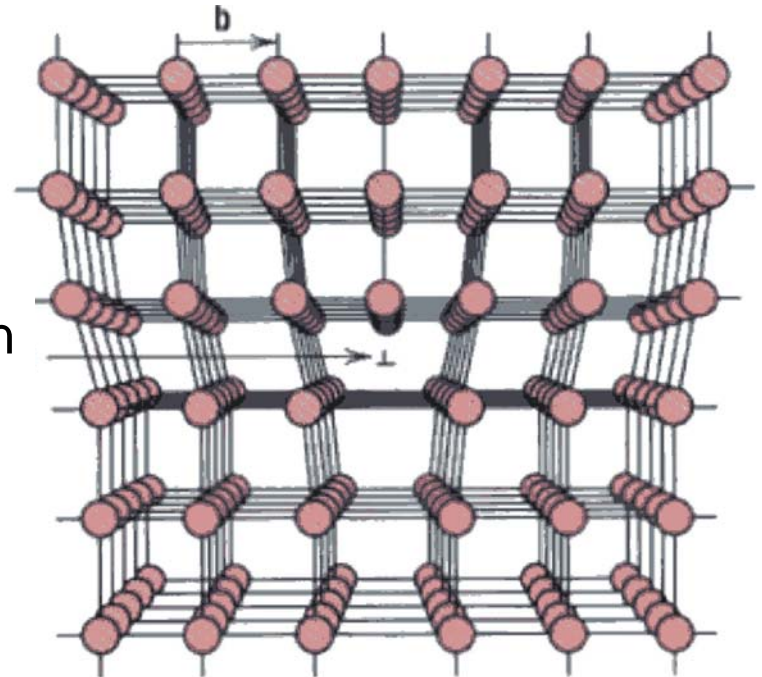


**It looks perfect.
But....**



**Edge
Dislocation
Line**

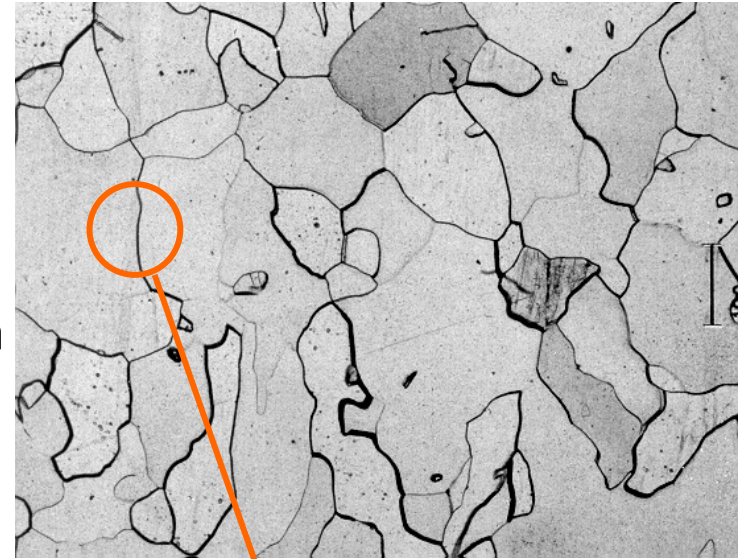
Burgers vector



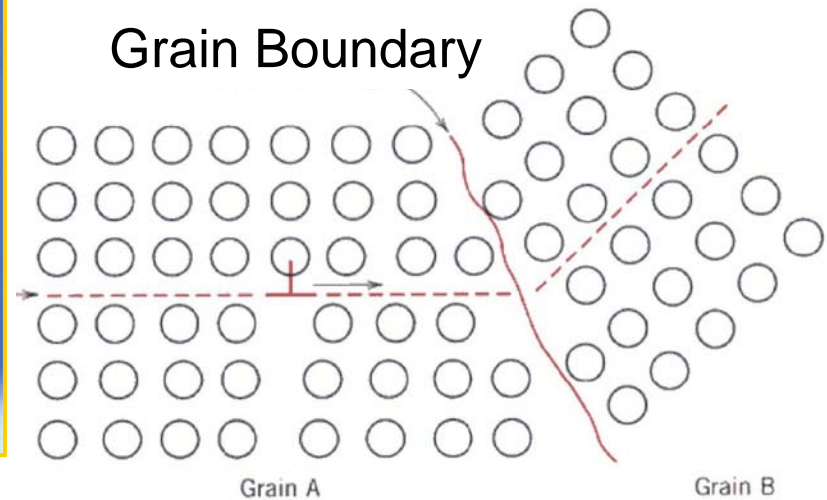
Grain Boundaries



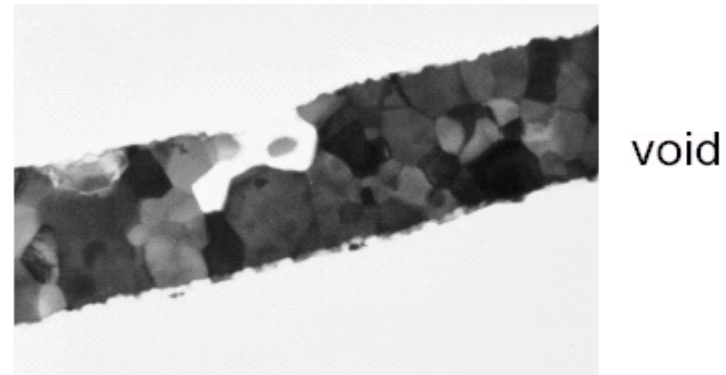
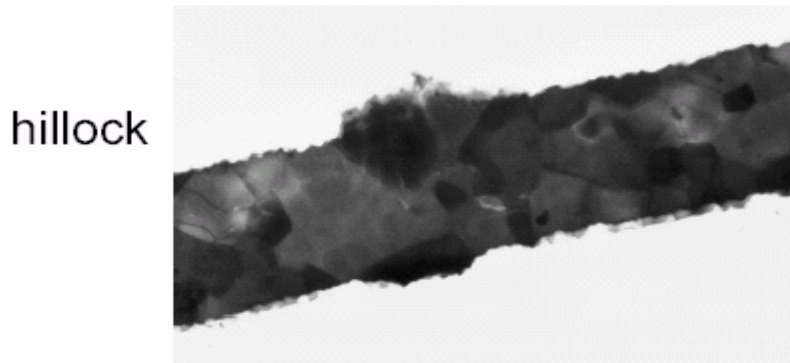
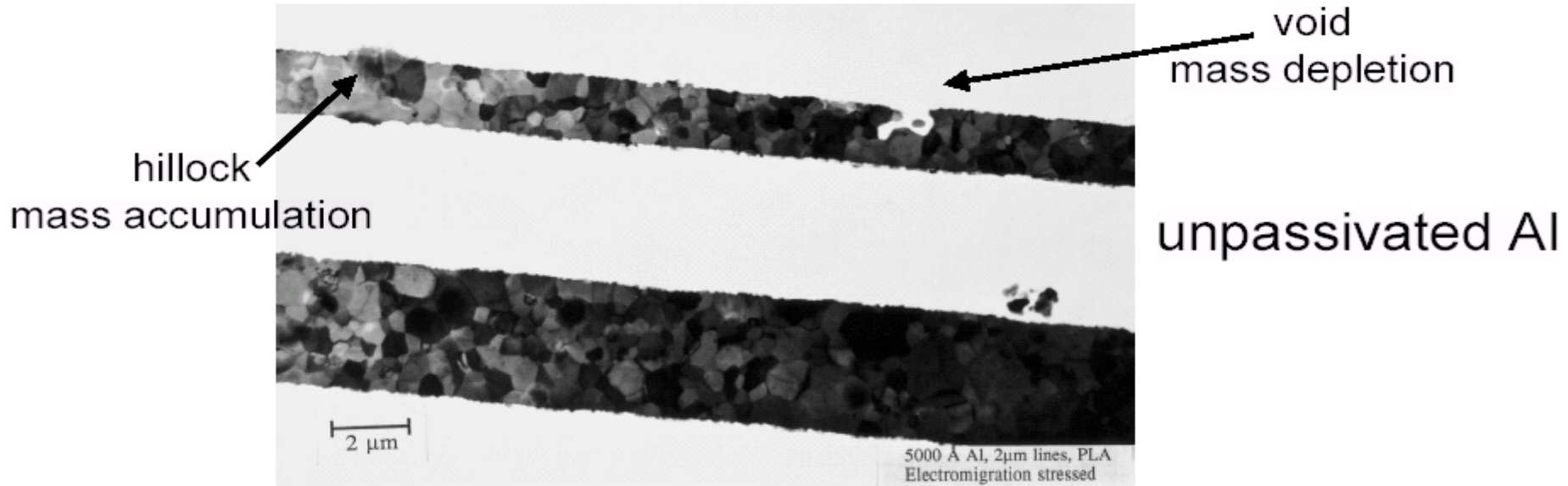
Low Carbon Steel



Optical
Microscope

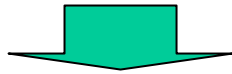


Voiding by Electro-migration in Interconnects



McKnelly, Sanchez, Morris, UC Berkeley, 1989

Using of Materials with Improper Microstructure



Failures

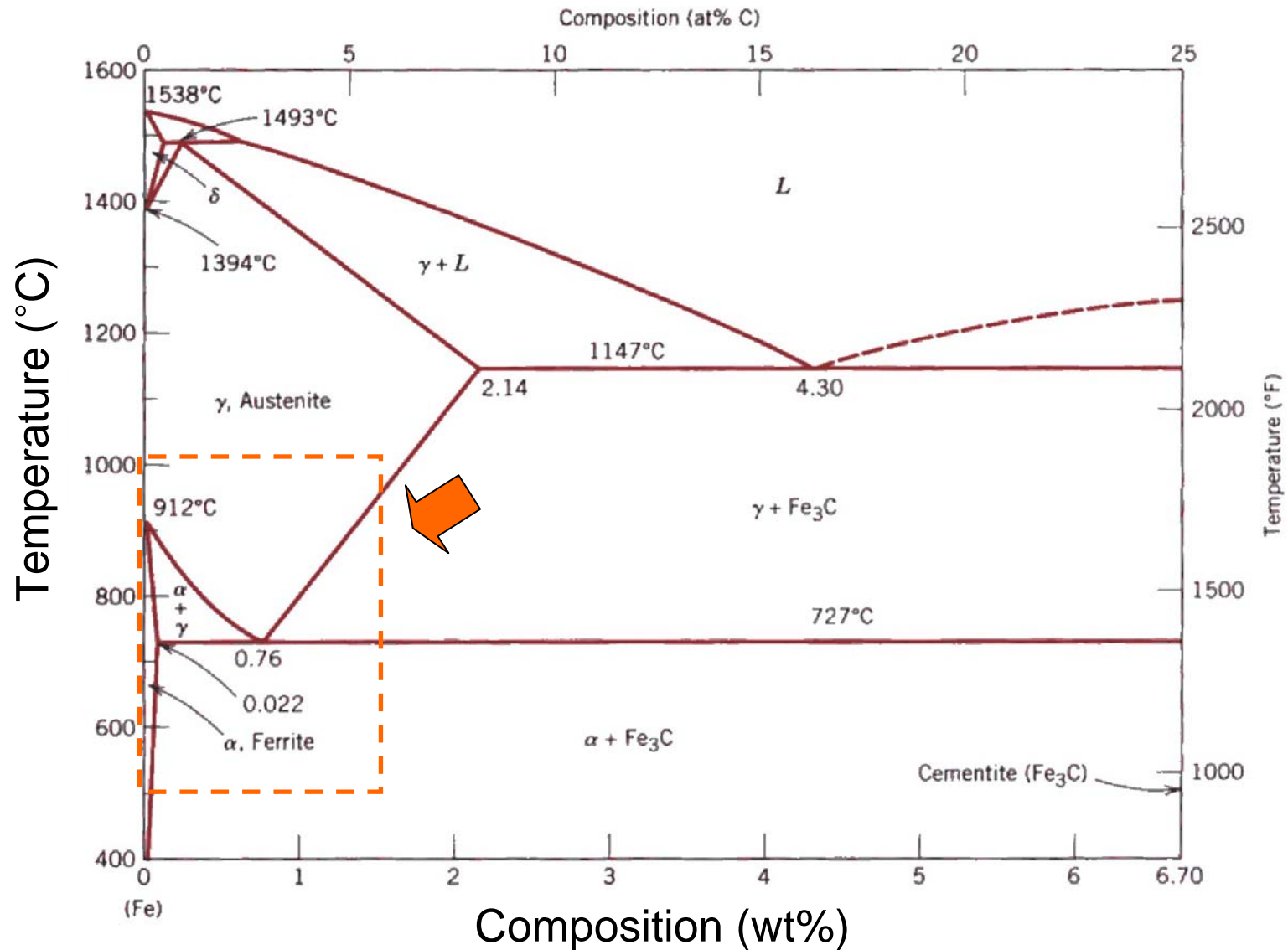


Oil tanker
fractured in a brittle manner

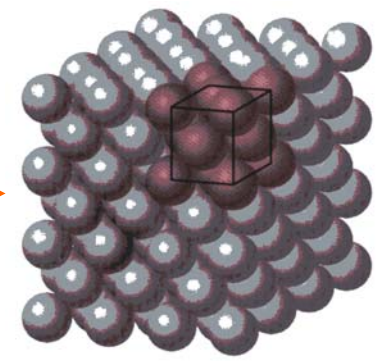
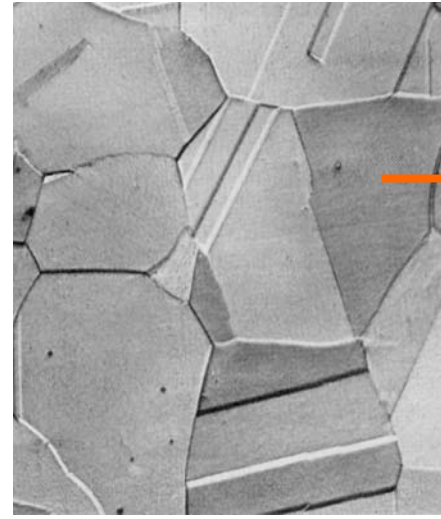
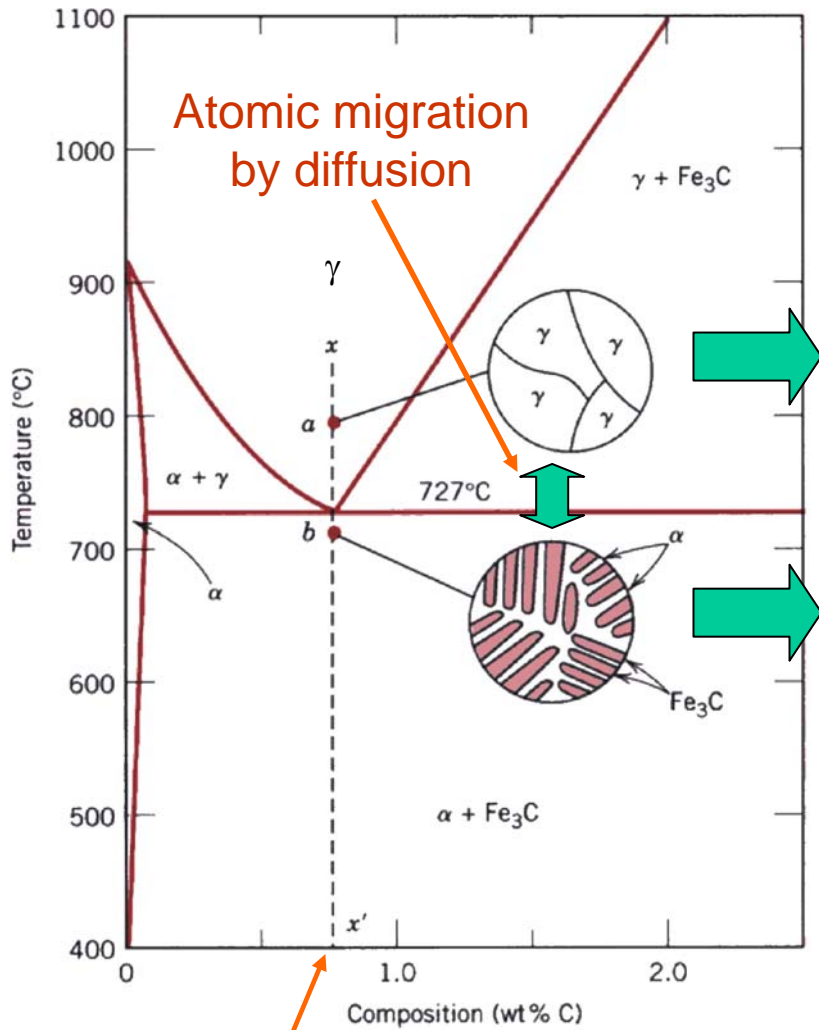


성수대교 붕괴 (1994.10.21)

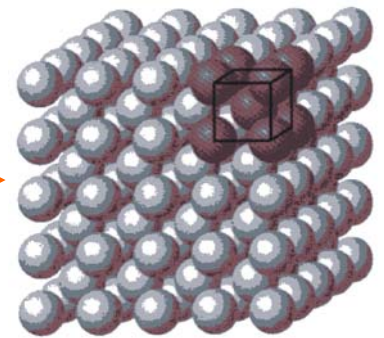
Phase Diagram of Iron–Carbon Alloy



Equilibrium Phases of Iron-Carbon Alloy



γ phase (FCC)

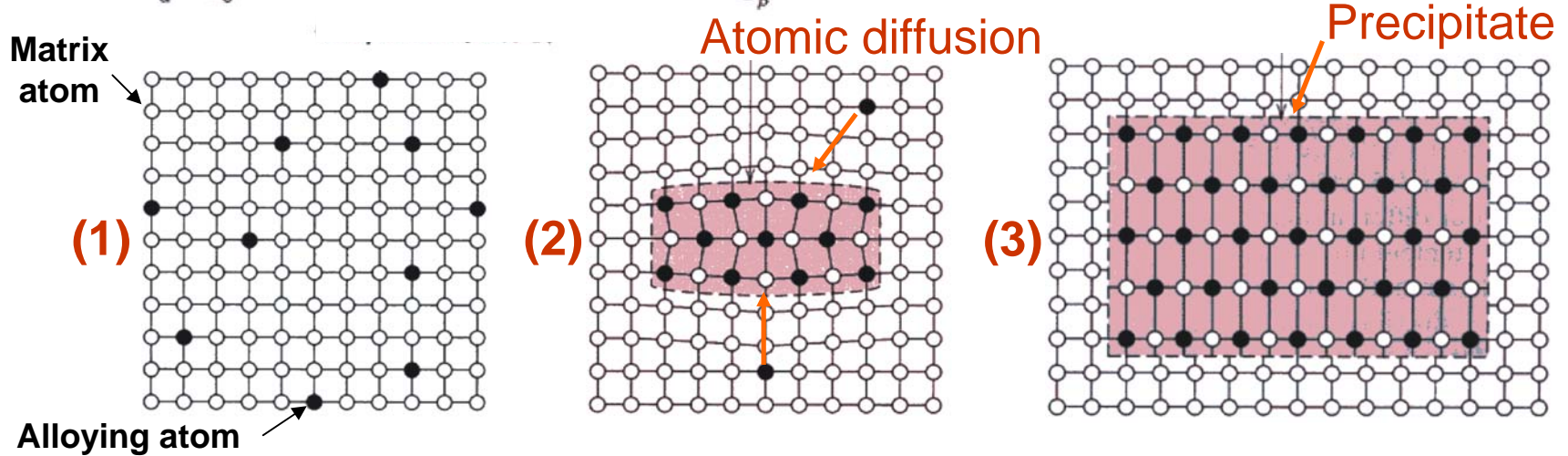
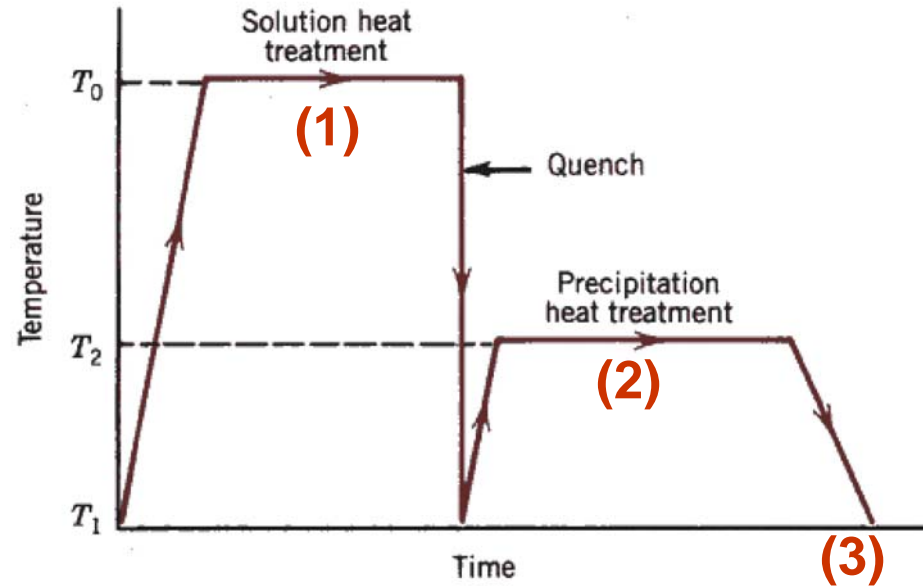
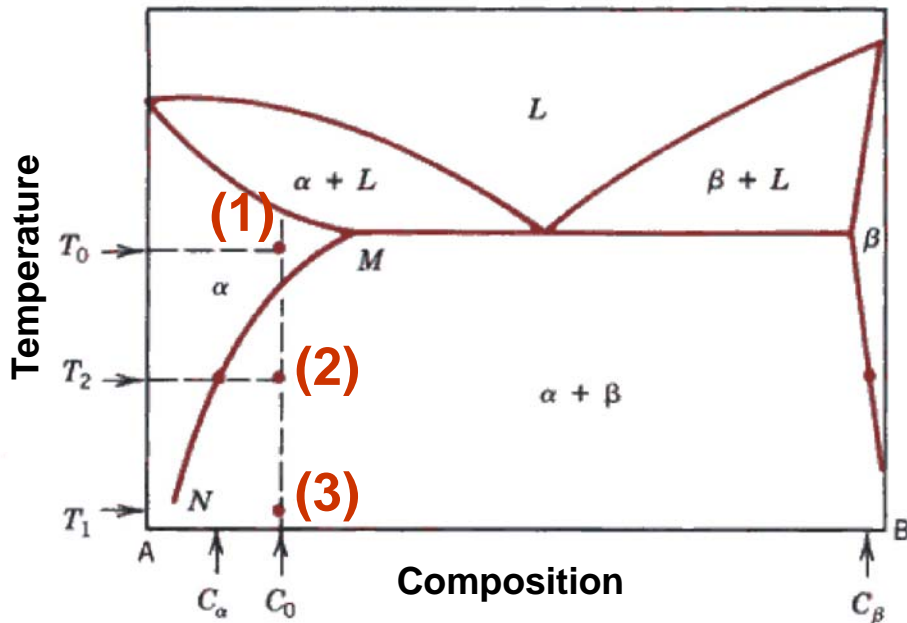


Fe_3C phase

α phase (BCC)

Eutectoid composition

Mechanism of Precipitation



Effect of Second Phase Particle on Mechanical Property

Second phase particle
in matrix material

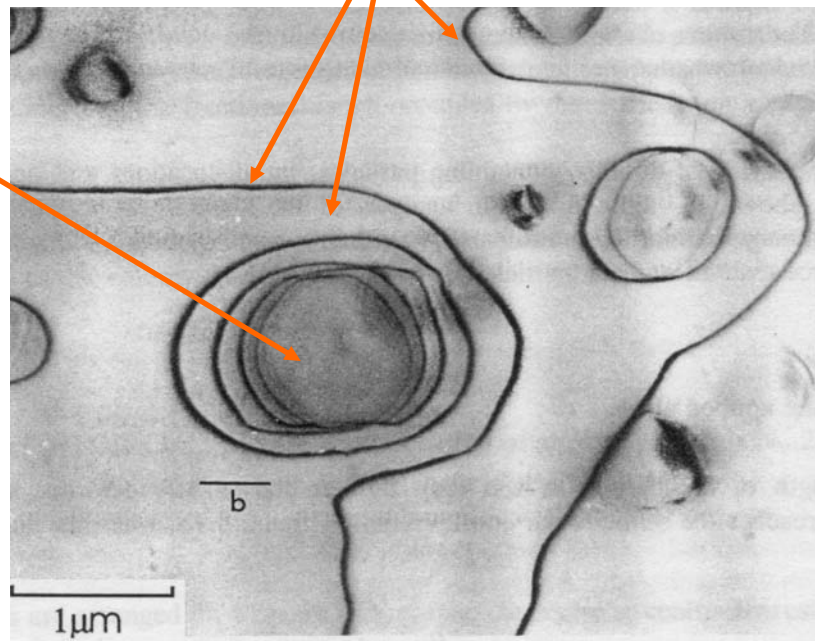


Obstacle of
dislocation slip
& grain growth



High strength

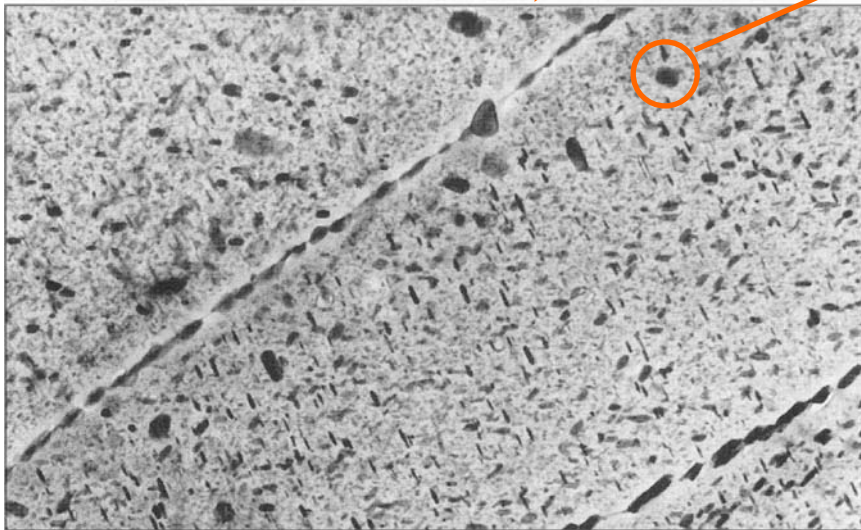
Dislocations



Ni₃Si particles in Ni-6%Si single crystal

Control of Microstructures by Precipitation Transformation in Aluminum Alloy

Boeing 767 by AA7150 T651 alloy



Precipitates
in aluminum matrix



Hindering dislocation slip



High strength

Control of Microstructures ; Cold Work

김홍도
“대장간”



조선시대



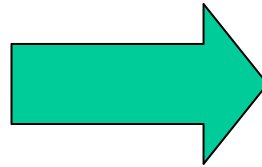
현대의 단조기

Hardening Mechanism by Cold Working



Before cold work

Deformation
or
Cold work



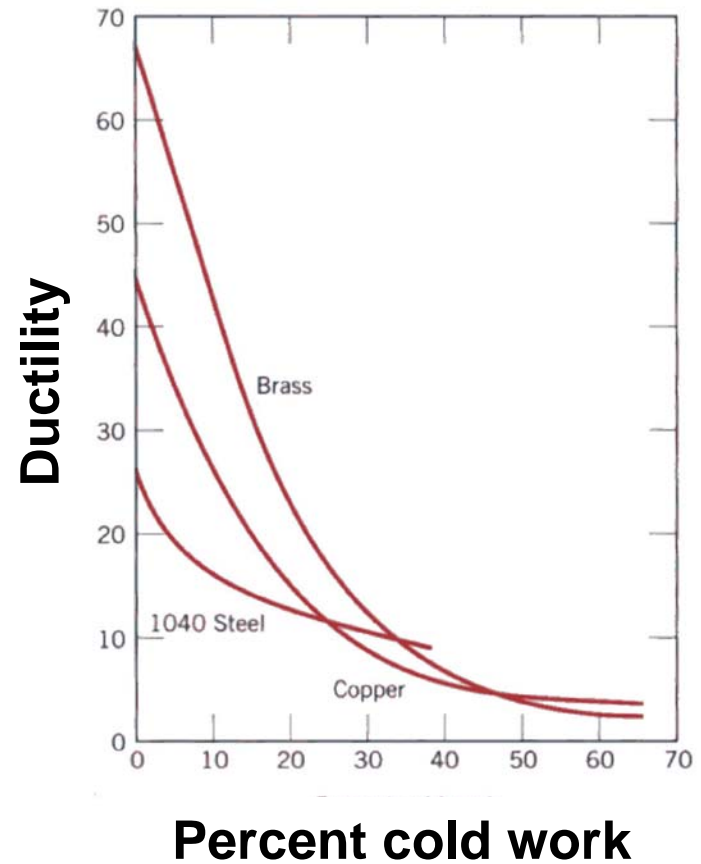
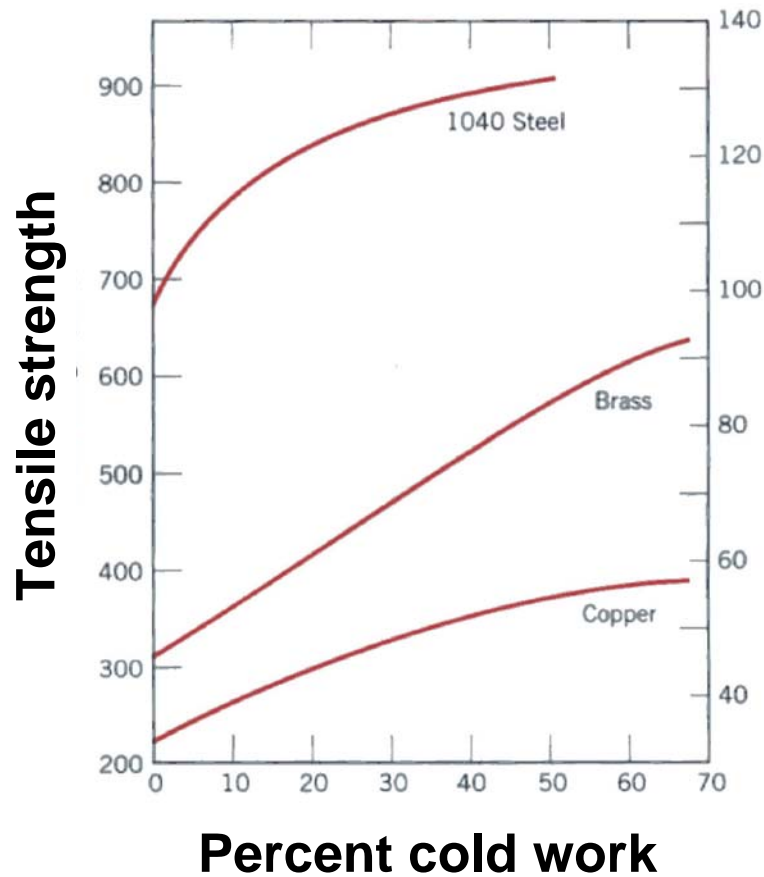
Aluminum alloy



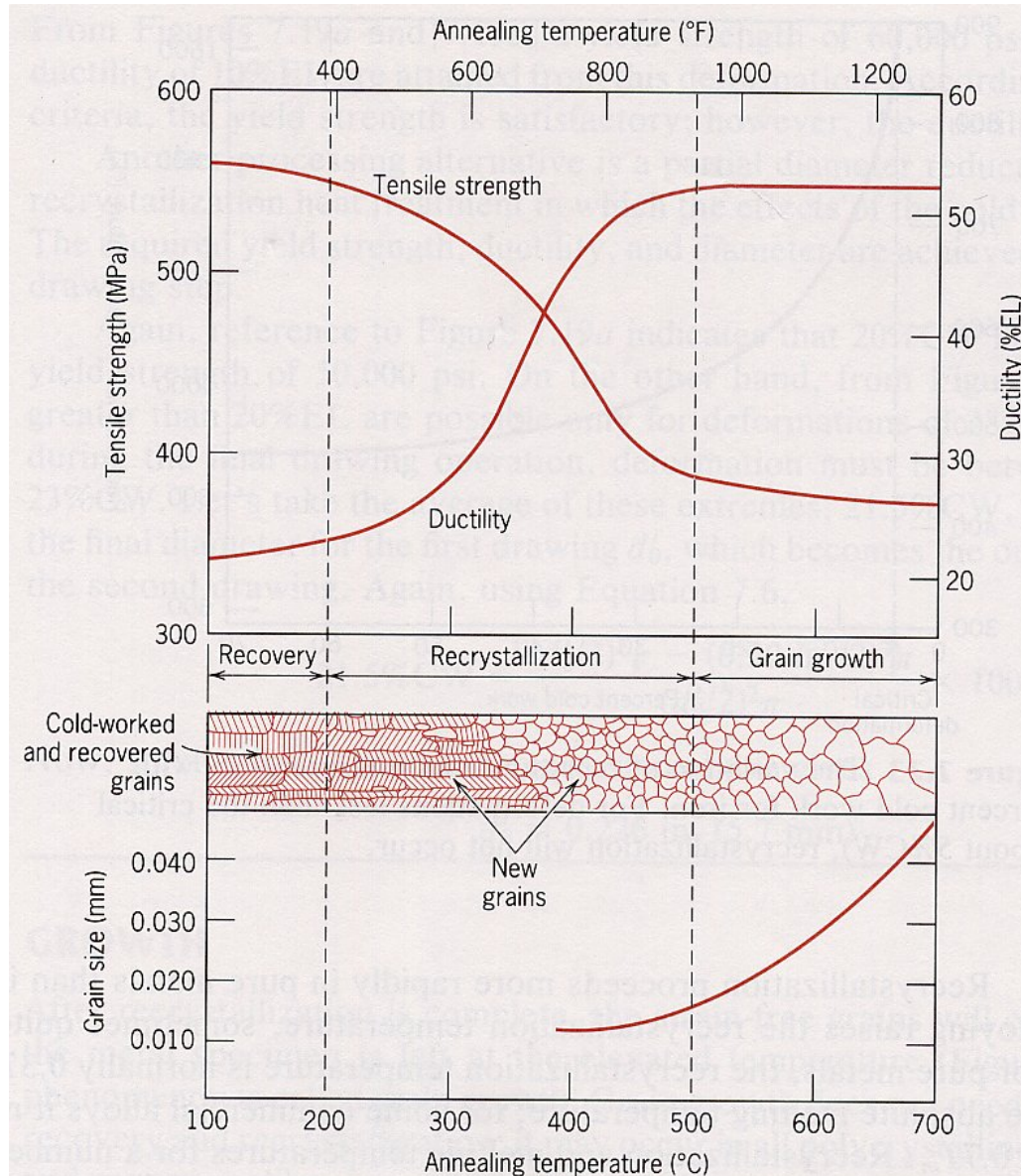
Accumulation
of dislocations

Dislocation tangle

Changes of Strength and Ductility by Cold Working



Changes of Microstructure & Mechanical Properties during Annealing



Production and Application of Electrical Steel

Hot rolling - cold rolling – 1st annealing – 2nd annealing



Coils



Stacked transformer core

Transformer
Motor
Etc.

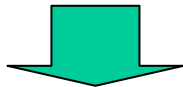


Soft magnetization property

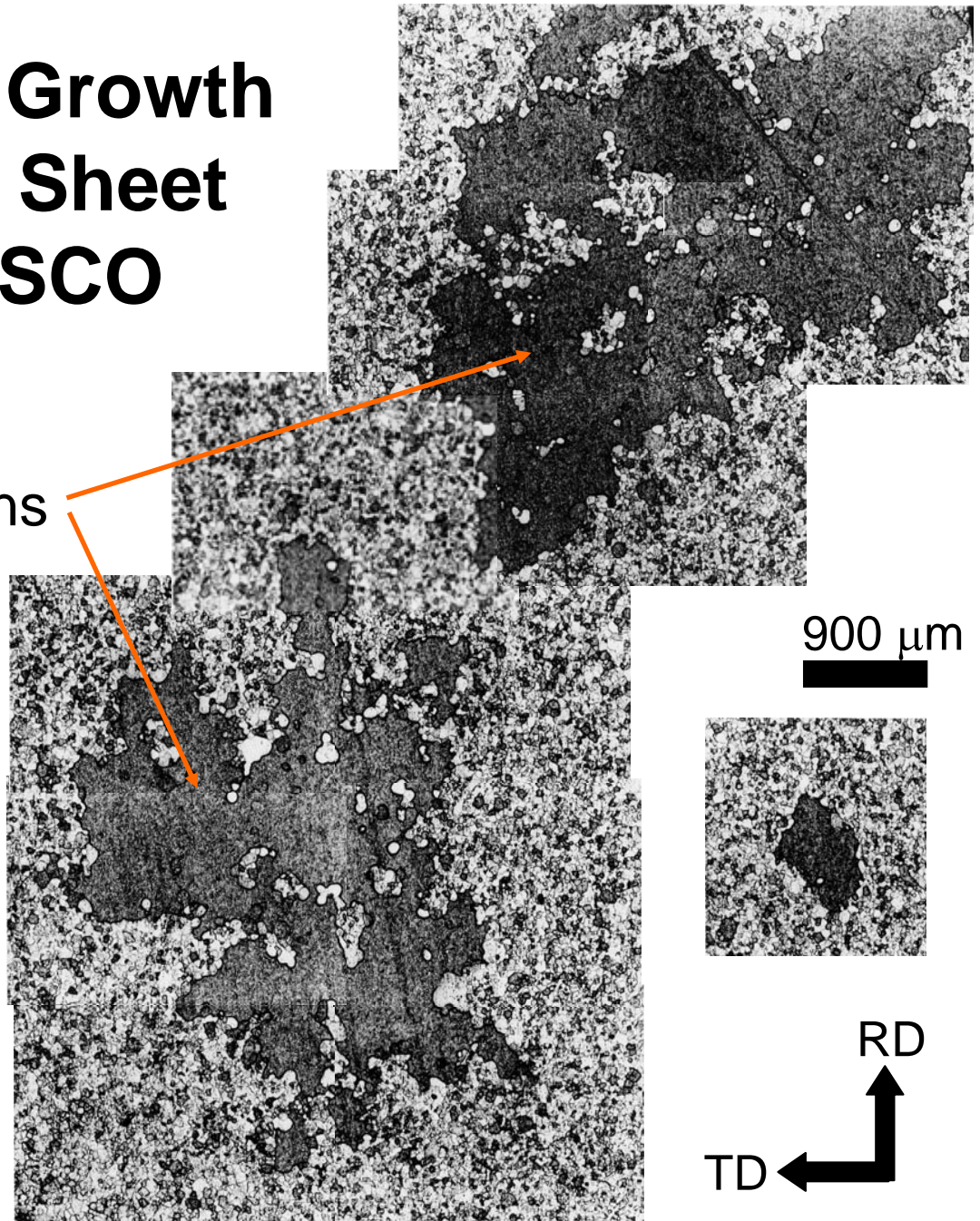
Abnormal Grain Growth In Fe-3%Si Steel Sheet produced by POSCO

Abnormally grown grains
with Goss texture

Control of grain growth



**Control of
magnetic property**



Production and Application of Electrical Steel

Hot rolling - cold rolling – 1st annealing – 2nd annealing



Coils



Stacked transformer core

Transformer
Motor
Etc.

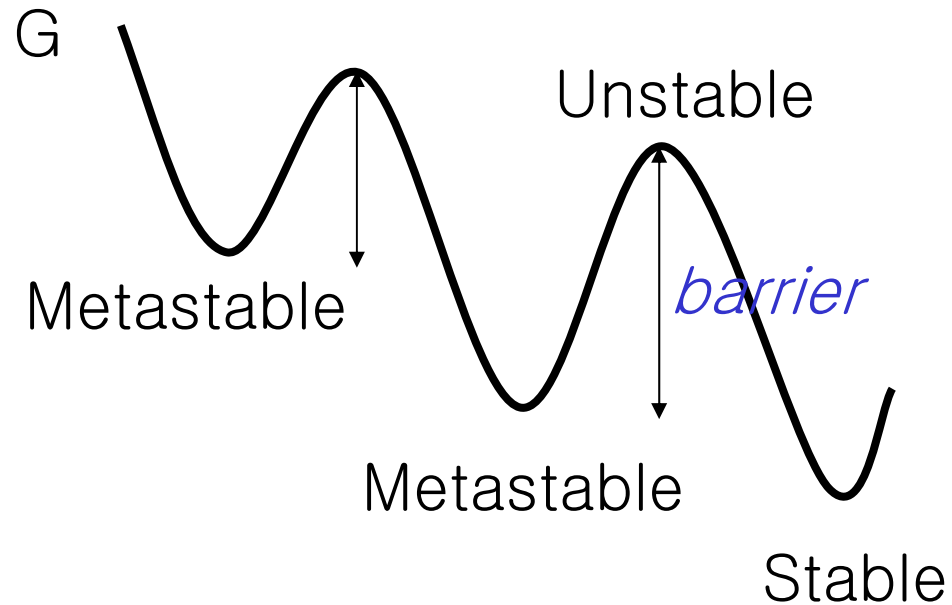


Soft magnetization property

Understanding and Controlling Phase Transformation of Materials

Phase Transformation

- Thermodynamics
- Kinetics



Phase Transformation

- **Solidification: Liquid \rightarrow Solid**
- **Phase transformation in Solids**

Diffusion-controlled phase transformation ;

Generally long-distance atomic migration

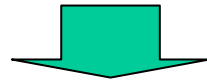
- Precipitation transformation
- Eutectoid transformation (**S \rightarrow S₁ + S₂**)
- etc.

Diffusionless transformation ;

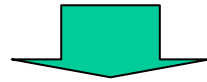
Short-distance atomic migration

- Martensitic transformation

**Time-Dependency of Diffusion-
Controlled Phase Transformation**

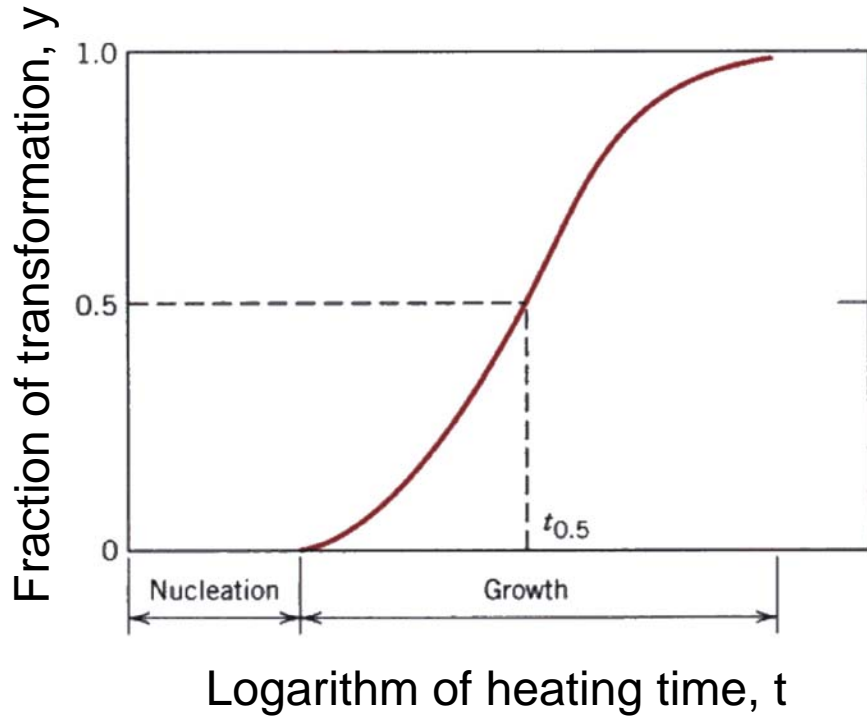


Non-Equilibrium Phases



**Need of Controlling
not only Temperature & Composition
but Process conditions (**Cooling Rate**)**

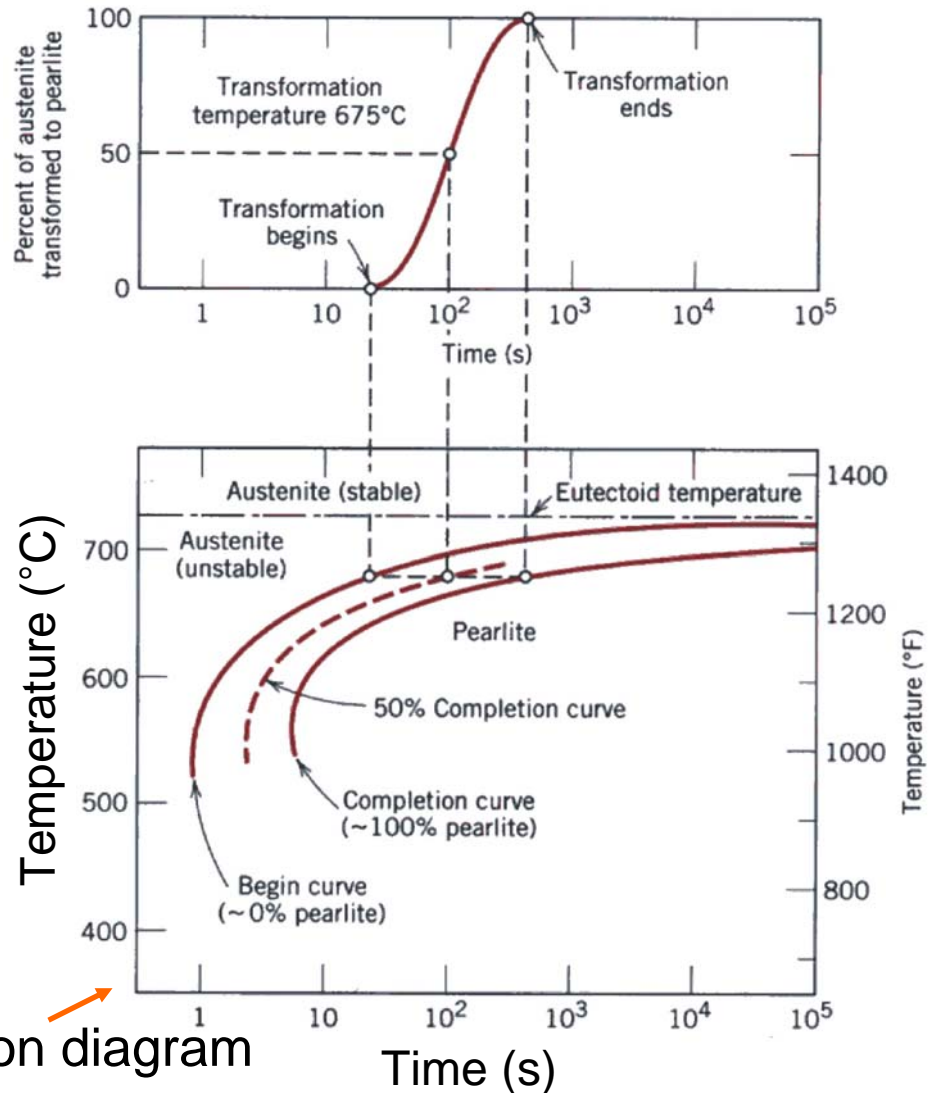
Transformation Kinetics and Isothermal Transformation Diagram



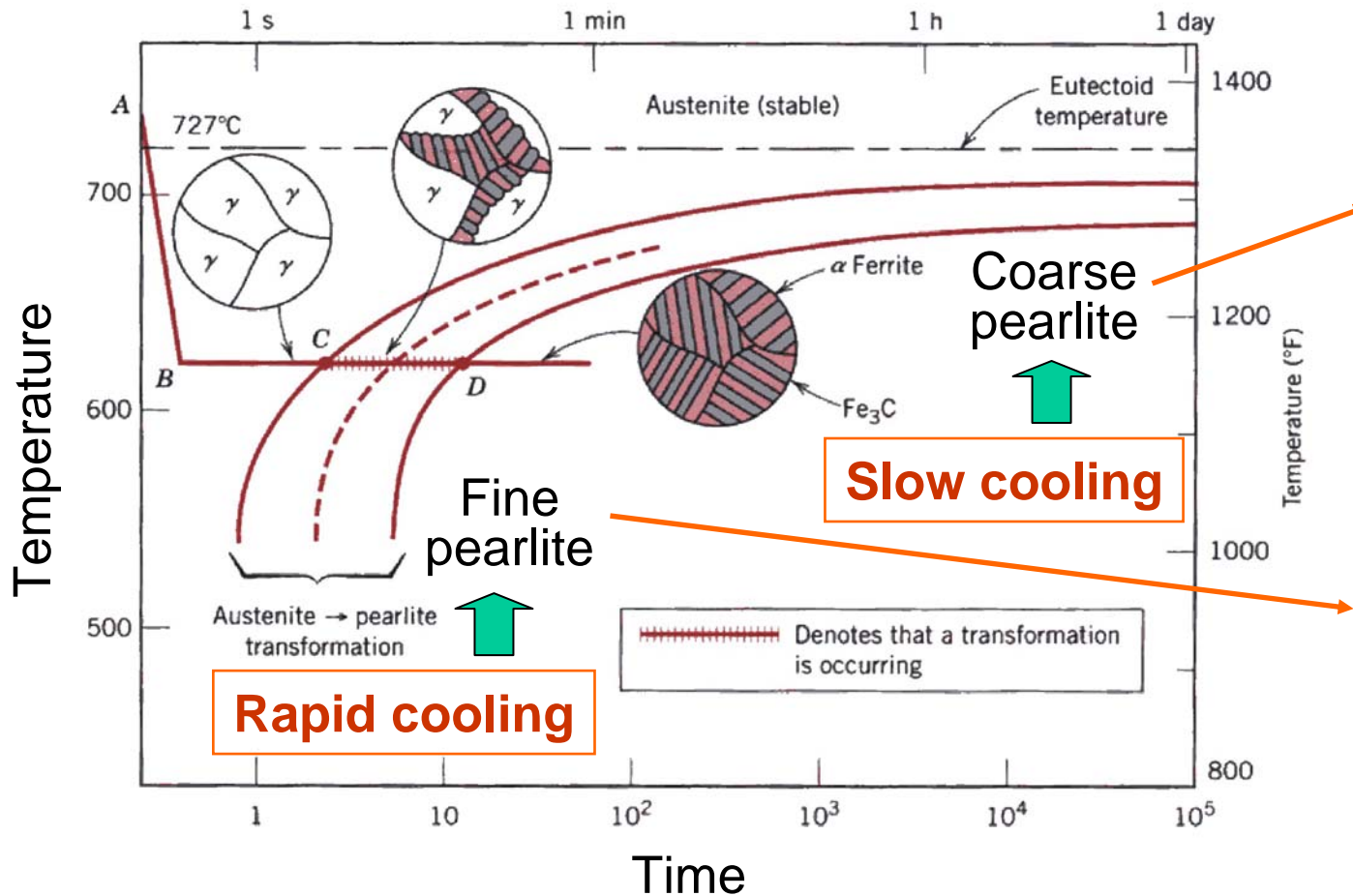
$$y = \exp(-kt^n)$$

Kinetics of diffusion-controlled solid-state transformation

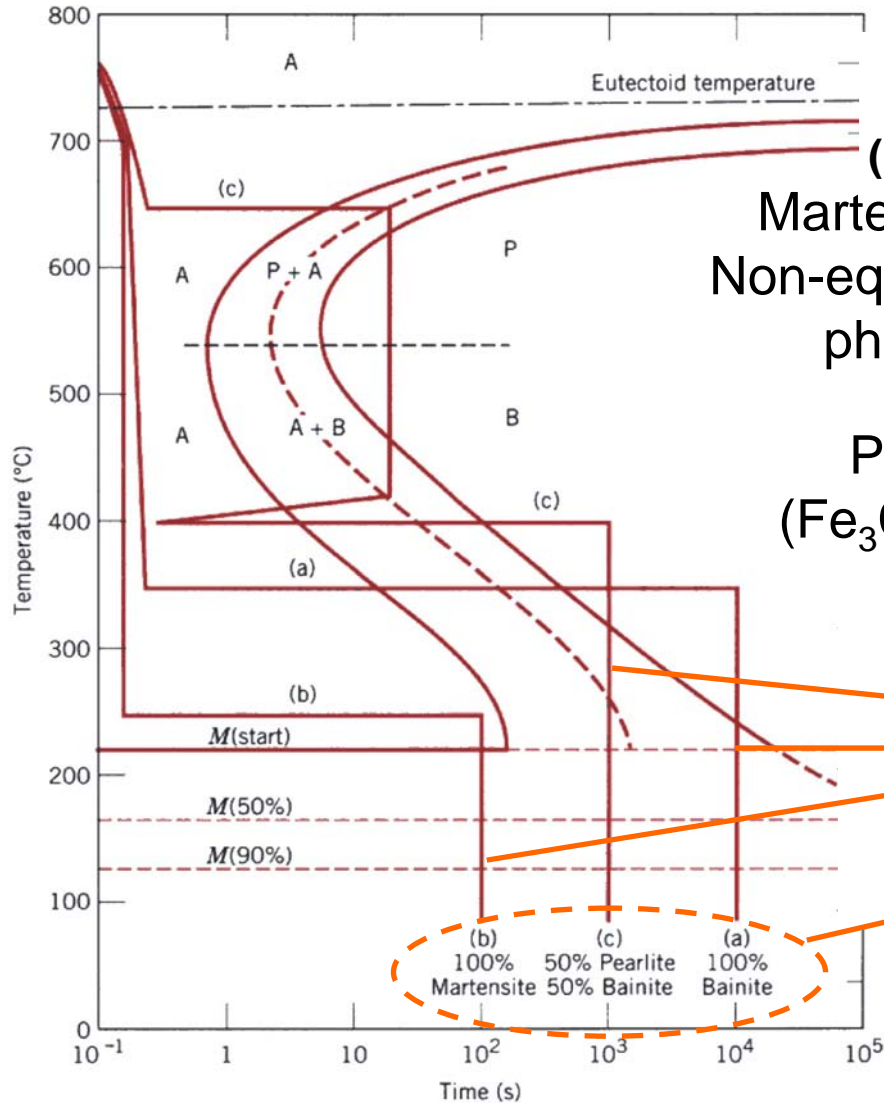
Isothermal transformation diagram



Isothermal Transformation Diagram of a Eutectoid Iron-Carbon Alloy

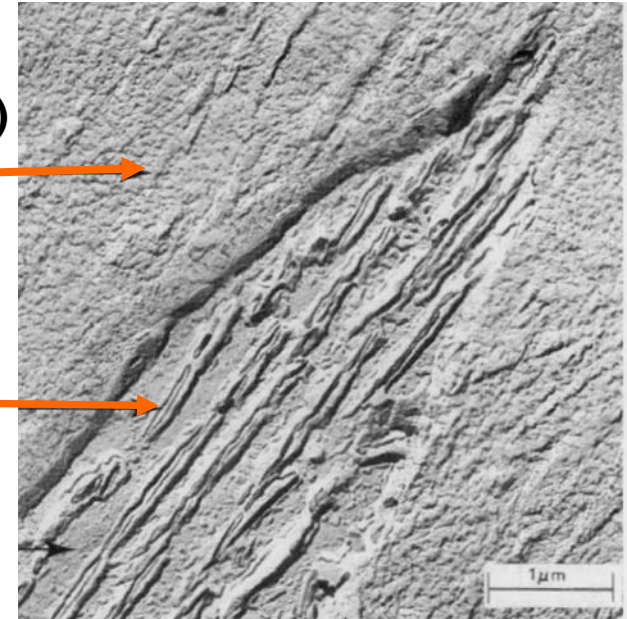


Control of Phases by Heat Treatment



(Very hard)
Martensite ;
Non-equilibrium
phase

Pearlite
(Fe_3C +ferrite)



Heat Treatment

Phase & Microstructure

Properties of Material

Control of Mechanical Properties by Proper Heat Treatment in Iron-Carbon Alloy

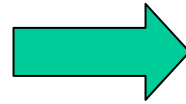


Martensite

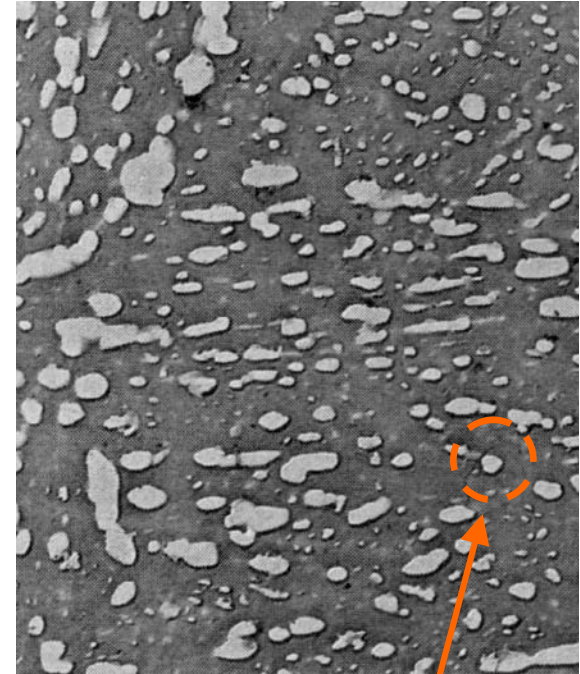
Tip of needle shape grain

Nucleation site of fracture

Brittle



Proper
heat treatment
(tempering)



Tempered martensite

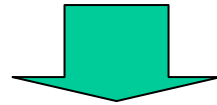
Very small & spherical shape grain

Good strength, ductility, toughness

Diffusionless Transformation

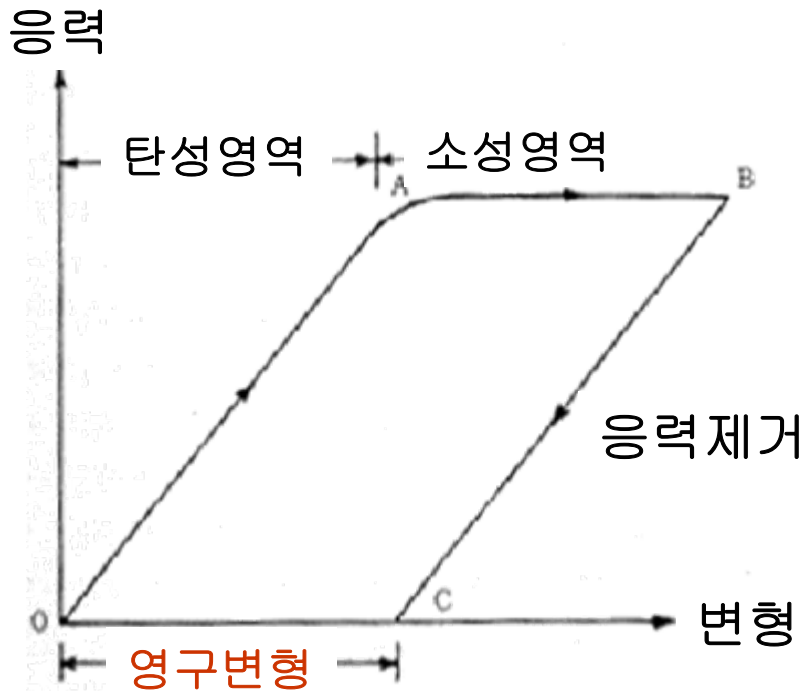
Martensitic transformation in iron-carbon alloy

**Martensitic transformation in Ni-Ti alloy ;
55~55.5wt%Ni-44.5~45wt%Ti (“Nitinol”)**

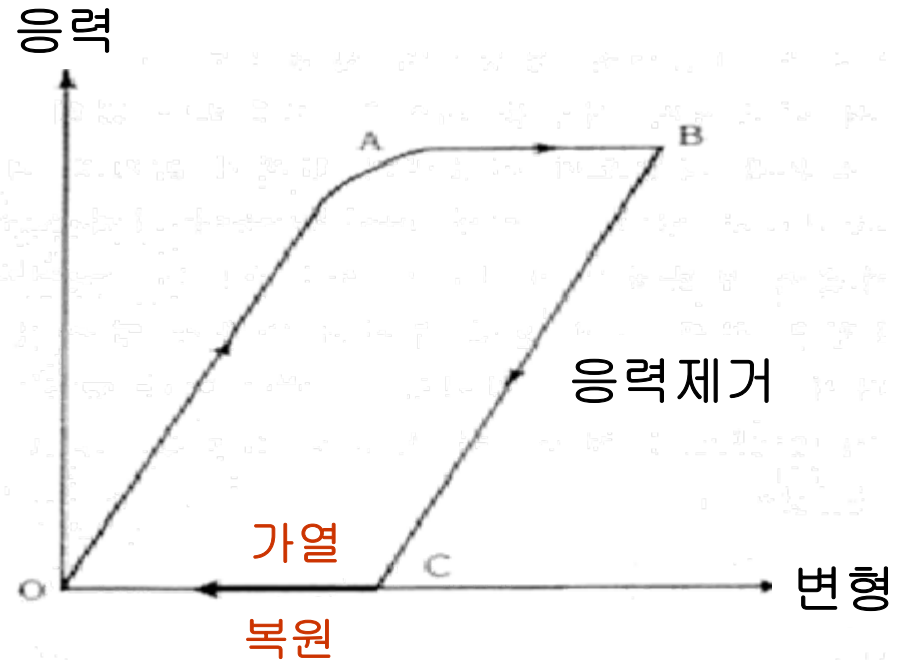


Shape memory alloy

Difference of Deformation Behavior between Conventional Metals and Shape Memory Alloys

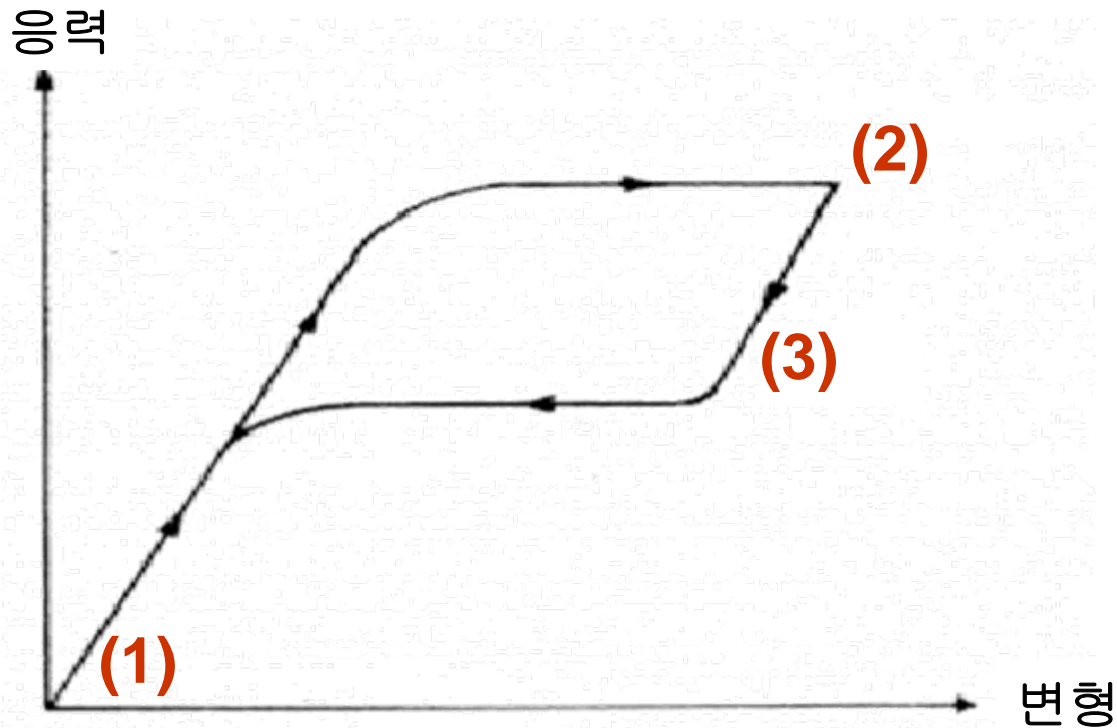


일반금속의 응력-변형 곡선



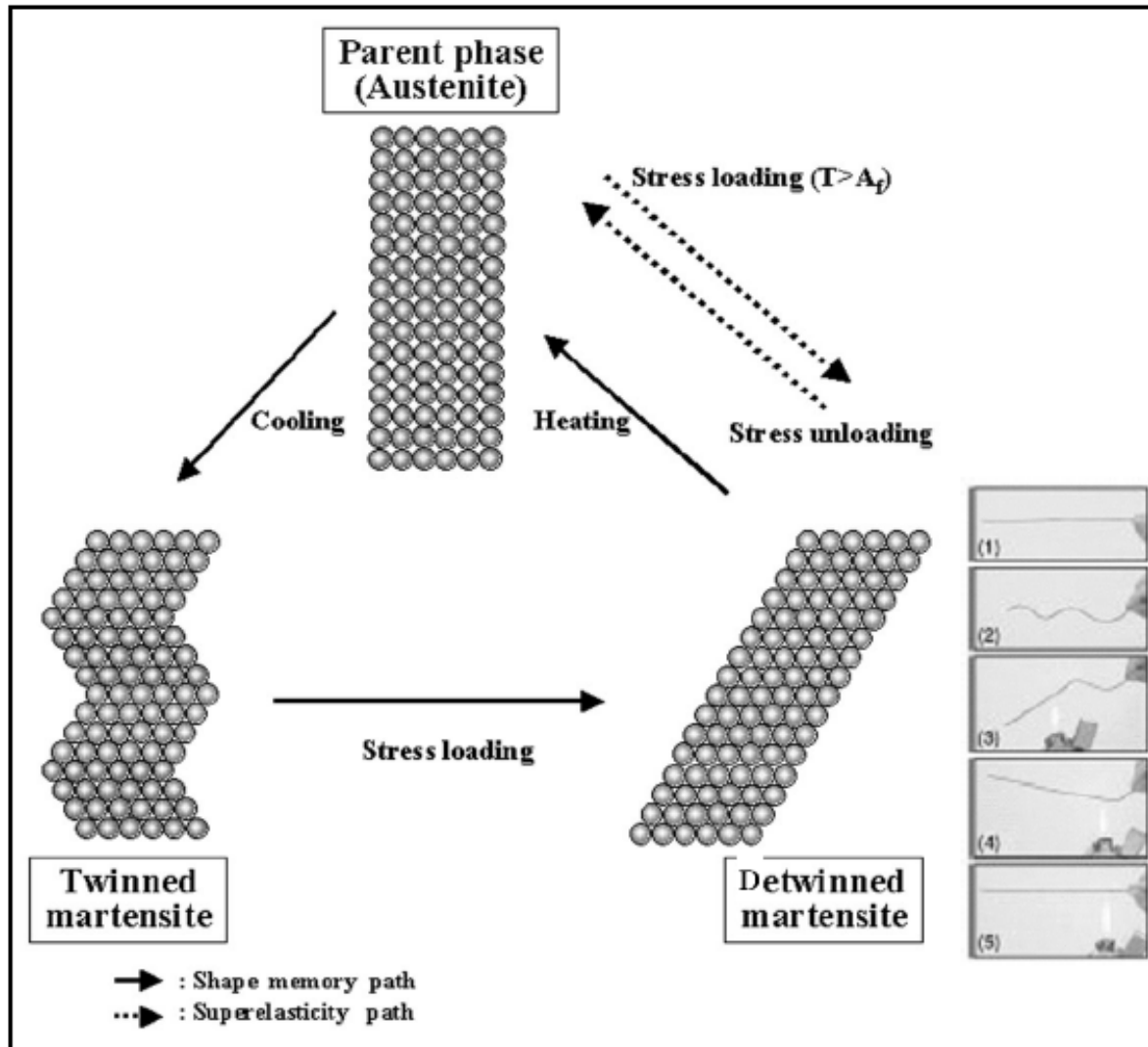
형상기억 합금의 응력-변형 곡선

Super-elasticity of Shape Memory Alloy

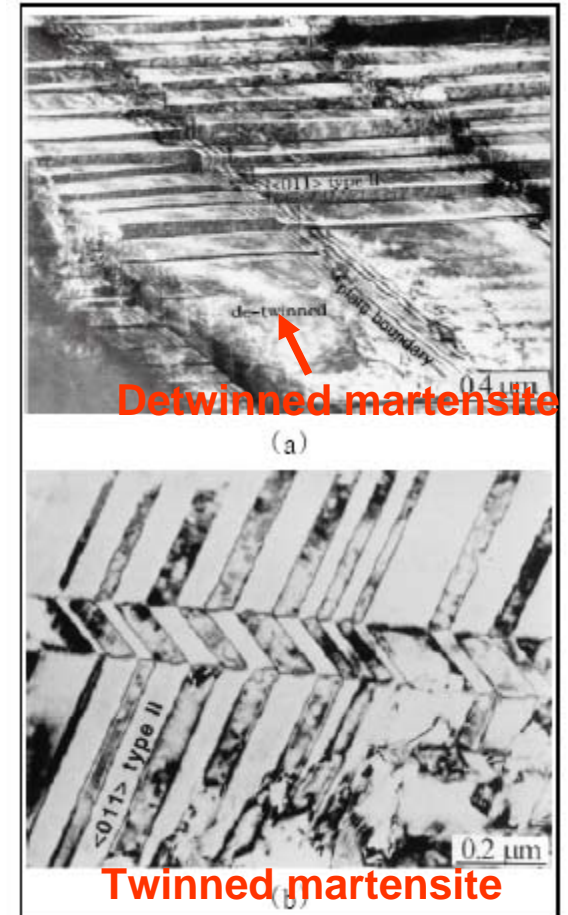


모상 (1) → 변형 (2) → 하중제거 (3) → 모상 (1)

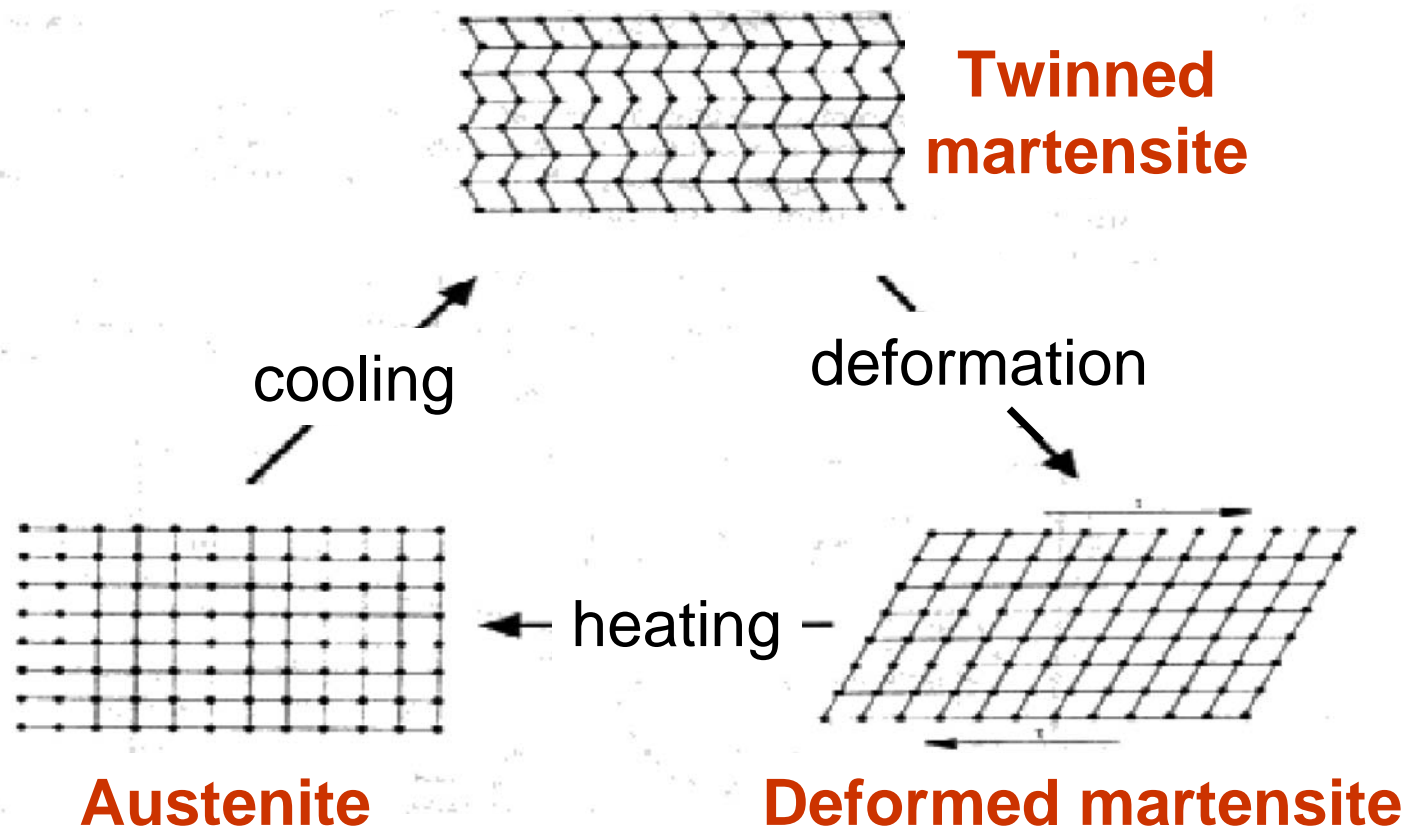
Principle of Shape Memory Alloys



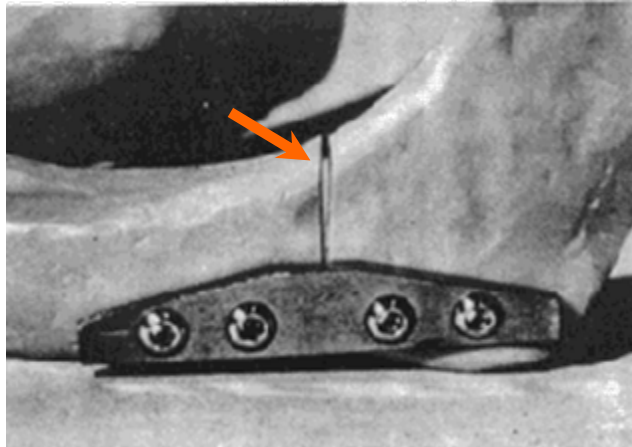
Ni-Ti alloys



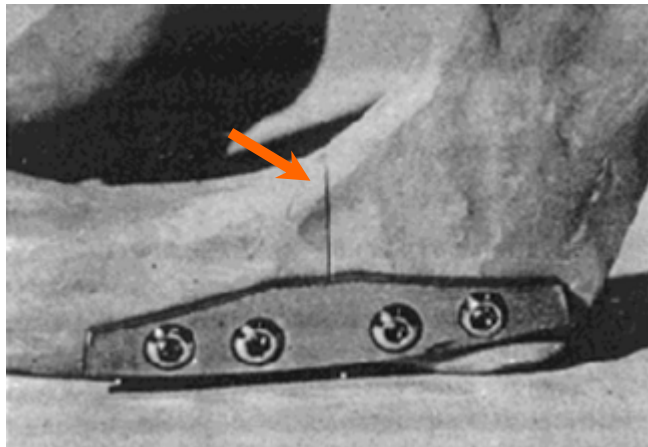
Change of Atomic Array during Martensitic Transformation in Ni-Ti Alloy



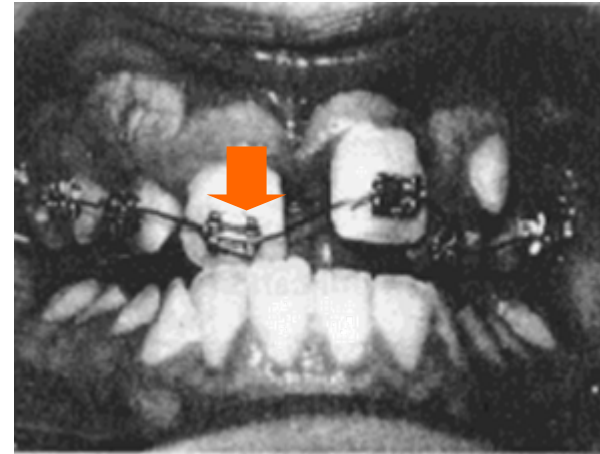
Medical Applications of Shape Memory Alloys



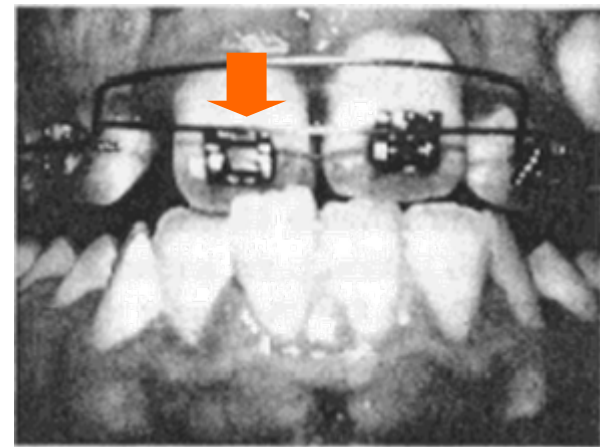
heating 



Bond-bonding staple



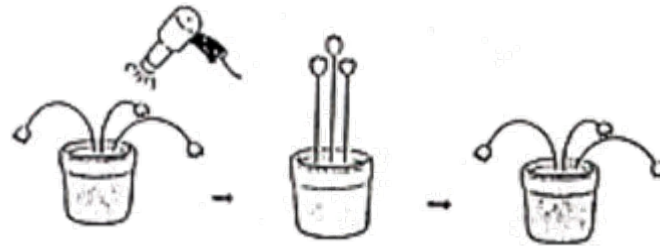
 After 3 weeks



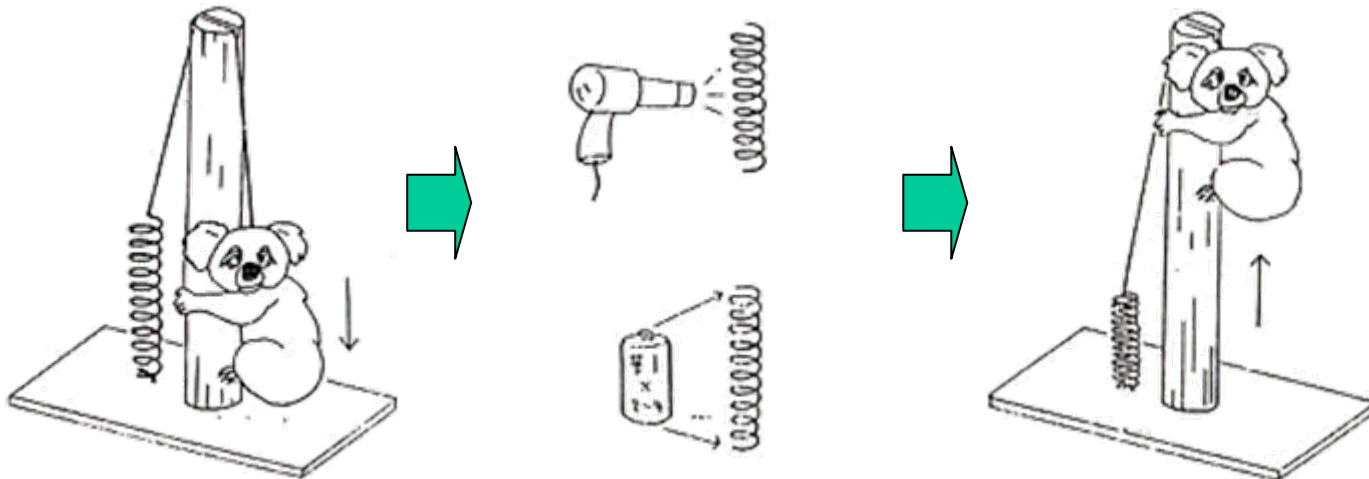
Wire for tooth-correction

Shape Memory Alloy's applications can be used in many ways depends on the use of YOUR IDEAS.

Magic flower



Magic spring (climb koala)



Contents in Phase Transformation

- **Thermodynamics (Ch1)**
- **Kinetics- Diffusion (Ch2)**
- **Microstructure: Interface, Grain structure (Ch3)**
- **Solidification: Liquid \rightarrow Solid (Ch4)**
- **Transformation: Solid \rightarrow Solid (Diffusional) (Ch5)**
- **Transformation: Solid \rightarrow Solid (Diffusionless) (Ch6)**

Materials Science and Engineering

공정(工程)

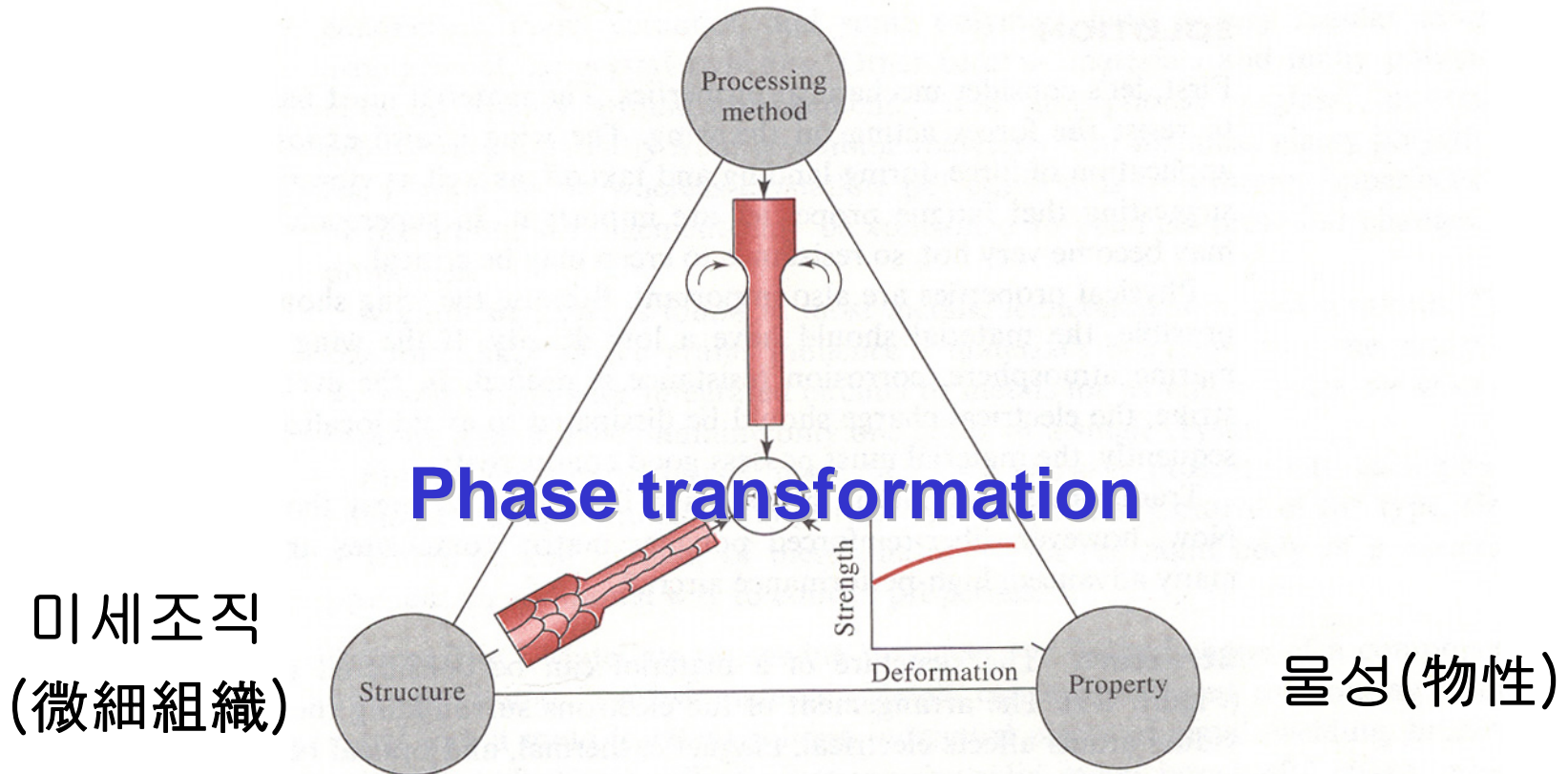


FIGURE I-8 The three-part relationship between structure, properties, and processing method. When aluminum is rolled into foil, the rolling process changes the metal's structure and increases its strength.

2008년 9월

일	월	화	수	목	금	토
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				