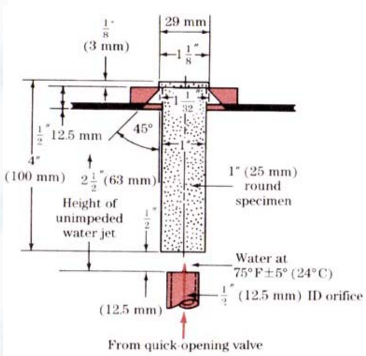
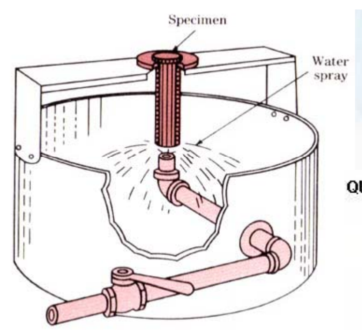
Chapter 11

Applications and Processing of Metal Alloys

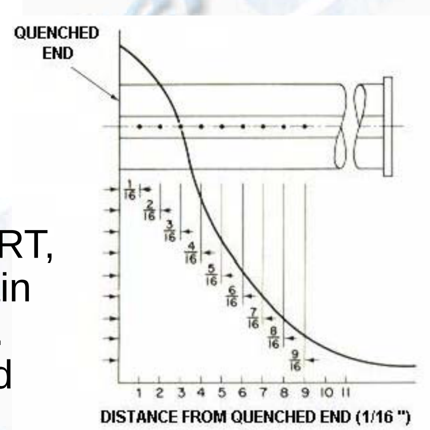
This is just an extension of the previous chapter…

Hardenability of Steels: The Jominy Test



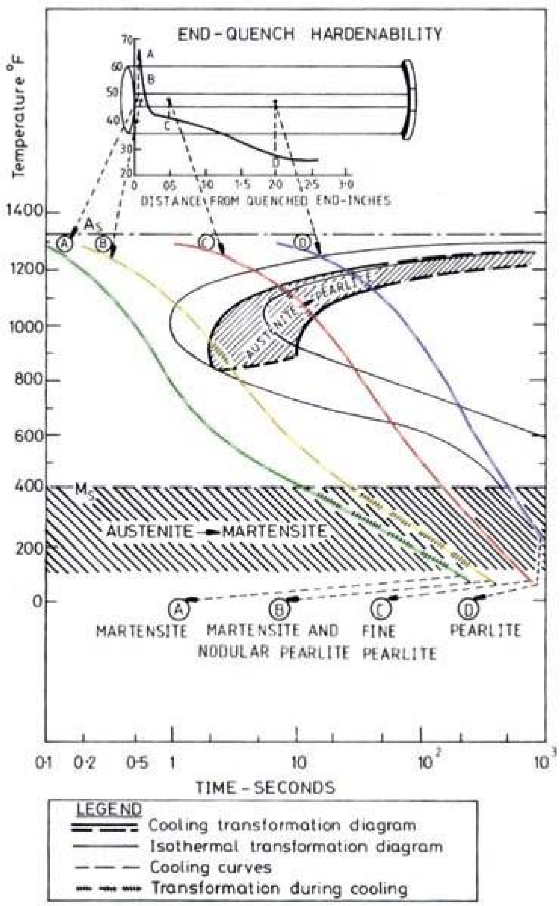


As usual, everything is standardized!



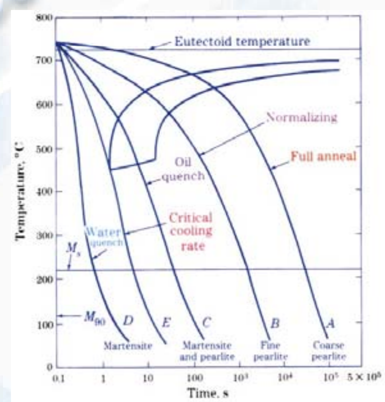
After the Jominy specimen cools to RT, hardness is measured along the main axis of the sample at 1/16" intervals. The resulting H vs. distance is called the "Jominy curve".

Hardenability of Steels



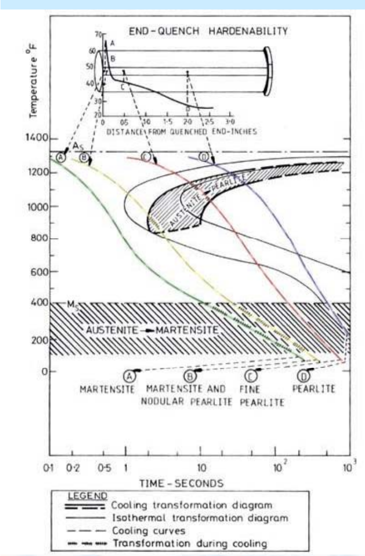
Notice the variation of hardness and the cooling rates with the distance from the quenched end.

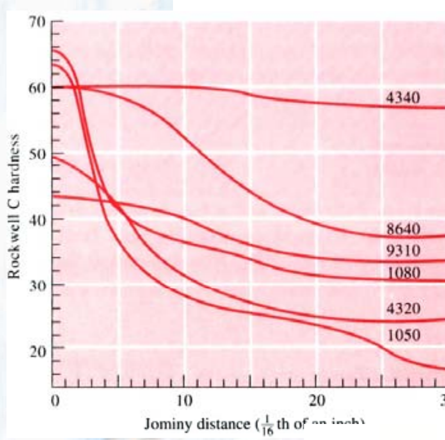
Would the cooling curves vary from steel to steel? What would they depend on?



For the exam, you need to know this correlation between cooling rate and resulting microstructures.

Hardenability of Steels (cont.)

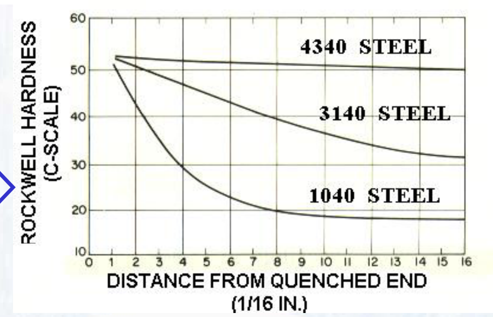




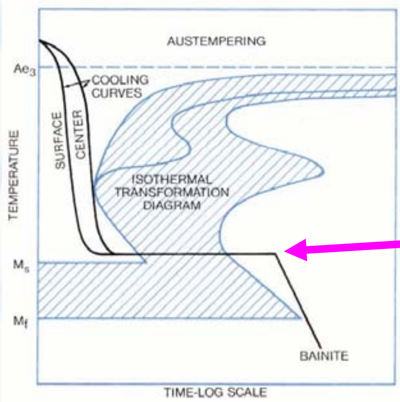
How do you predict the hardenability of a steel by “reading” the Jominy curves?

Examples

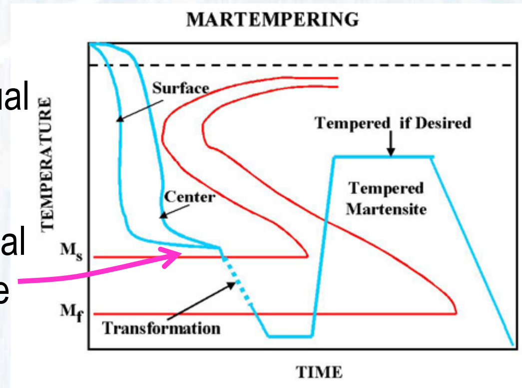
In this graph, we have the opportunity of assessing the effect of certain alloying elements on hardenability while the level of carbon is kept constant (0.40 wt.%)



Specialized Heat Treatments



Austempering: Used in order to produce a 100% bainitic structure that has a high yield strength. Note that the isothermal treatment is conducted a few degrees above M_S. Why?



Martempering: Used in order to avoid residual stresses caused by differential cooling (surface, core) in large parts. It forms 100% martensitic structure. Note that the isothermal treatment is conducted a few degrees above M_S for short time.

Specialized Surface Heat Treatments (Hardening)

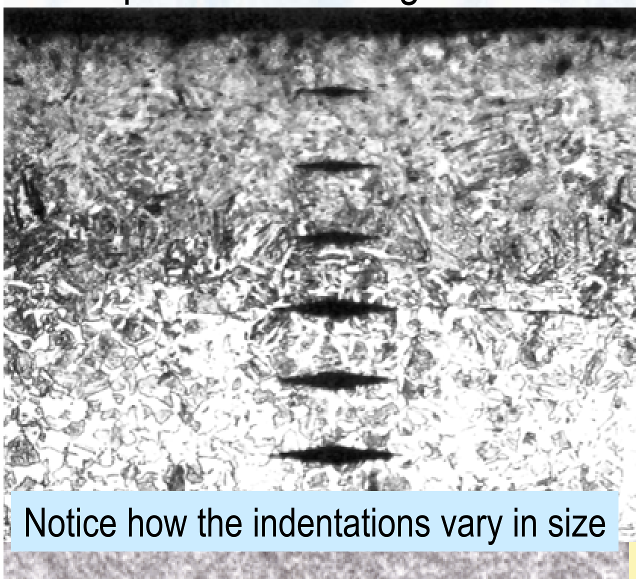
Required for:
- Wear resistance
- When the most severe stresses act only on the surface
- To increase the the lifetime of the part subject to cyclic stress

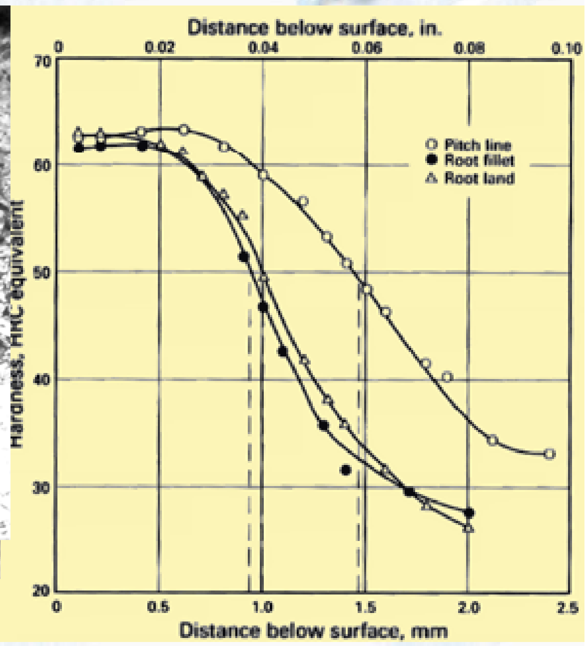
Can be done:
- By localized heating and quenching
- By modifying the chemical composition on and near the surface:
  - Carburizing
  - Nitriding
  - Carbonitriding
  - Chromizing, etc.

Please, give examples of possible applications

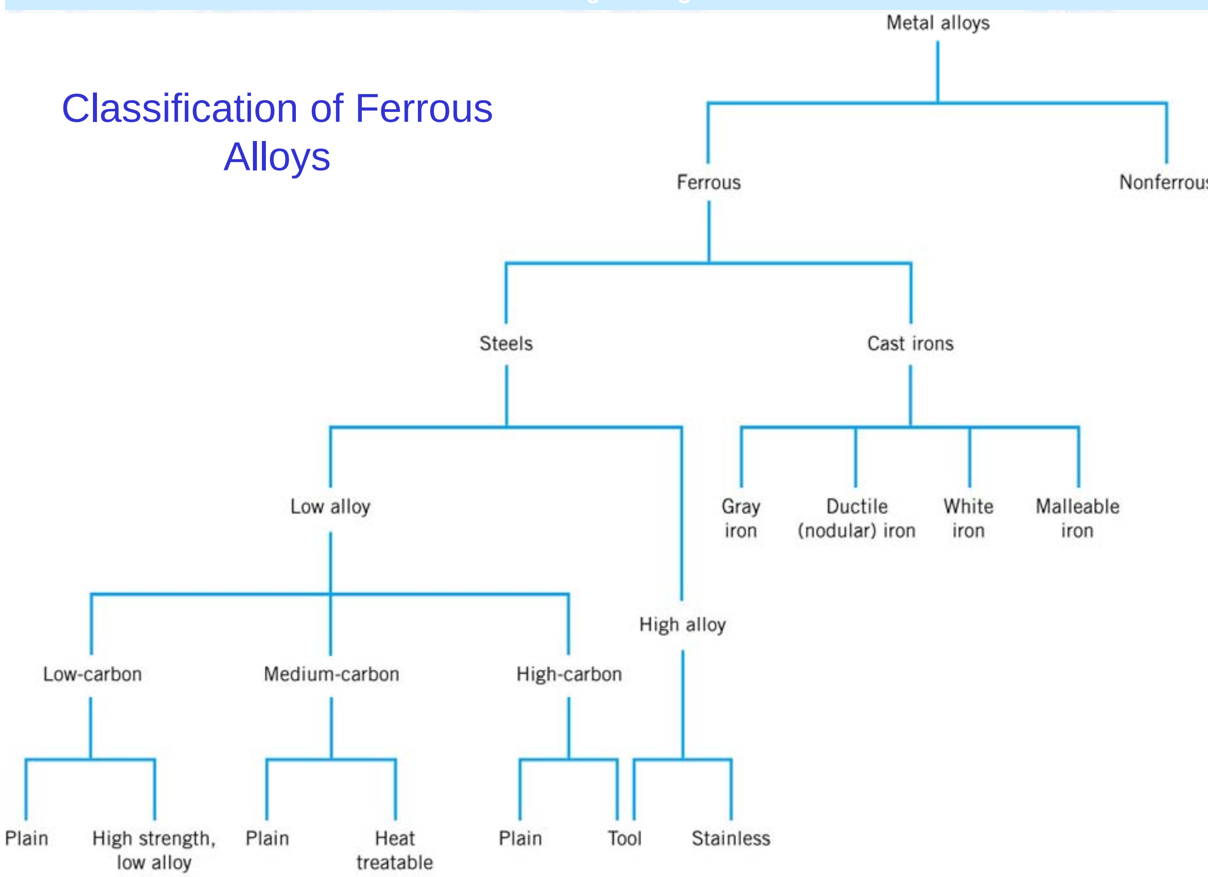
Surface Hardening: Carburizing

Surface diffusion of carbon in a gas furnace at austenization temperature. Starting material: low or medium carbon steels.





Classification of Ferrous Alloys



Designation of Steels (AISI / SAE)

Major groups in the SAE steel designation system

Class	SAE series	Major constituents
Carbon steels	10xx	Carbon steel
	11xx	Resulfurized carbon steel
Alloy steels		
Manganese	13xx	Manganese 1.75%
	15xx	Manganese 1.00%
Nickel	23xx	Nickel 3.50%
	25xx	Nickel 5.00%
Nickel–chromium	31xx	Nickel 1.25%, chromium 0.65 or 0.80%
	33xx	Nickel 3.50%, chromium 1.55%
Molybdenum	40xx	Molybdenum 0.25%
	41xx	Chromium 0.5 to 0.95%, molybdenum 0.12 to 0.20%
	43xx	Nickel 1.80%, chromium 0.50 or 0.80%, molybdenum 0.25%
	46xx	Nickel 1.80%, molybdenum 0.25%
	48xx	Nickel 3.50%, molybdenum 0.25%
Chromium	51xx	Chromium 0.80, 0.88, 0.93, 0.95, or 1.00%
	52xxx	Chromium 1.45%
Chromium–vanadium	61xx	Chromium 0.80 or 0.95%, vanadium 0.10 or 0.15% min.
Multiple alloy	86xx	Nickel 0.55%, chromium 0.50%, molybdenum 0.20%
	87xx	Nickel 0.55%, chromium 0.50%, molybdenum 0.25%
	92xx	Silicon 2.00%, or 1.40% and chromium 0.7%
	93xx	Nickel 3.25%, chromium 1.20%, molybdenum 0.12%
	94xx	Manganese 1.00%, nickel 0.45%, chromium 0.40%, molybdenum 0.12%
	94Bxx*	Nickel 0.45%, chromium 0.4%, molybdenum 0.12%

*denotes boron

ASTM Designation of Construction Steels

ASTM designation	General description	Recommended uses	Minimum yield stress, ksi	Minimum tensile strength, ksi
A36	Carbon steel	Bolted or welded buildings, bridges, etc.	36 (32 for t > 8")	58-80
A529	High-strength, low-alloy carbon-manganese steel	Bolted or welded buildings, bridges, etc.	42-50	60-100
A572	High-strength, low-alloy Niobium-Vanadium steel	Bolted or welded buildings	42-65	60-80
A242	Atmospheric corrosion-resistant high-strength, low-allow steel	Bolted or welded construction; welding technique critical	42-50	63-70
A588	Atmospheric corrosion-resistant high-strength,low-allow steel	Bolted construction	42-50	63-70
A514	Quenched and tempered low-alloy	Primarily welded construction; welding technique critical;	90-100	100-130
A992	High-strength, low-alloy	Replacing A36 and A572	50	65

Stainless Steels

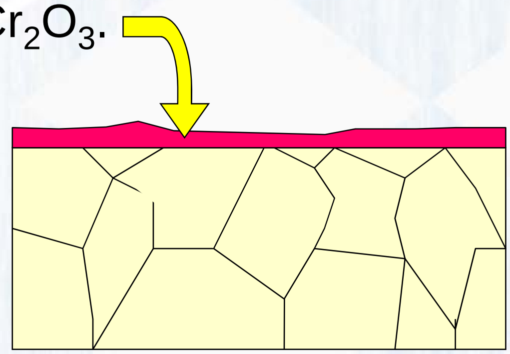
Corrosion resistant steels

Their corrosion resistance is due to the large amount of Chrome present:

-more than 12 wt.% Cr

The effect of Cr is to form a *passive* layer or protecting oxide layer of Cr_2O_3.

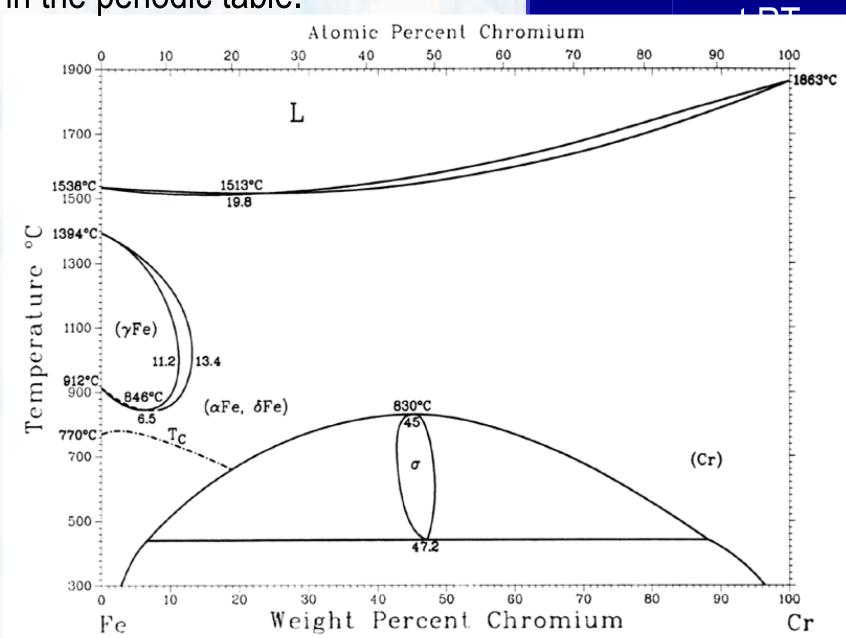
In first contact with the environment the material oxidizes but the oxide does not progress inside



Stainless Steels: Fe-Cr alloys

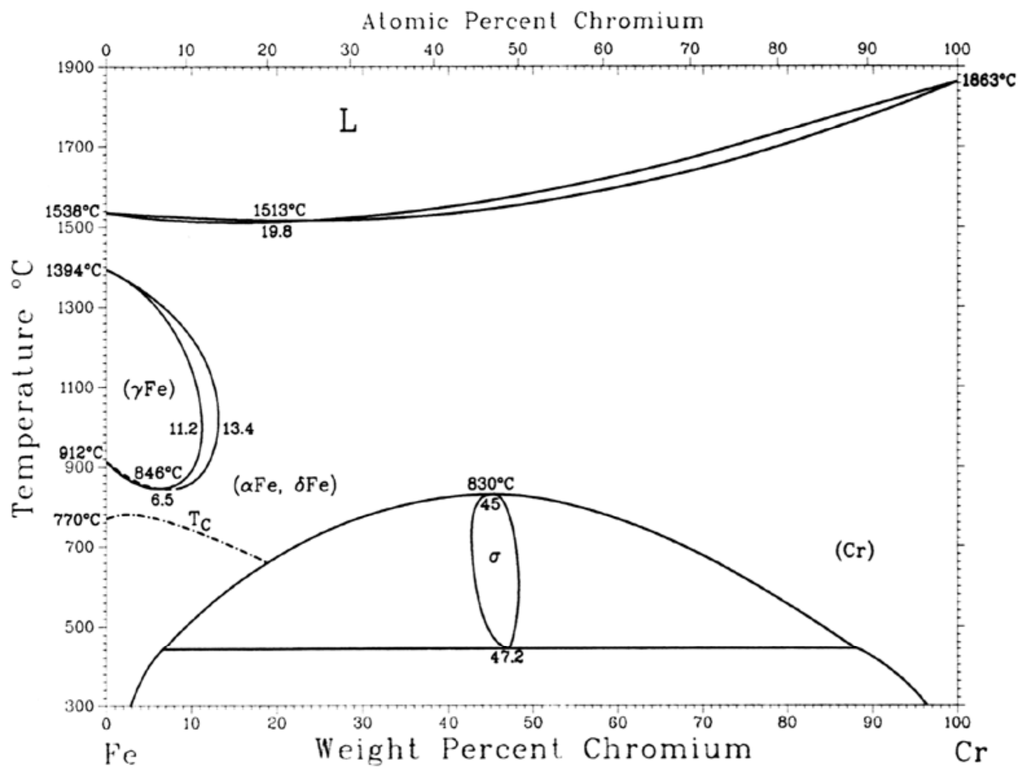
Remember where Fe and Cr are in the periodic table.

	Crystal Structure at RT	Atomic Radius (nm)	Electro-negativity
		0.124	1.7
		0.128	1.6



What do you suspect of both metals?

Stainless Steels: The Fe-Cr Phase Diagram



Stainless Steels Classification

It depends on the microstructural conformation of the steels:

- Ferritic Stainless Steels
- Martensitic Stainless Steels
- Austenitic Stainless Steels

Ferritic Stainless Steels

From 12 to 30% Cr with small amounts of carbon (0.012-0.20%)

Matrix: ferritic (α-Fe solution) with fine carbide precipitates.

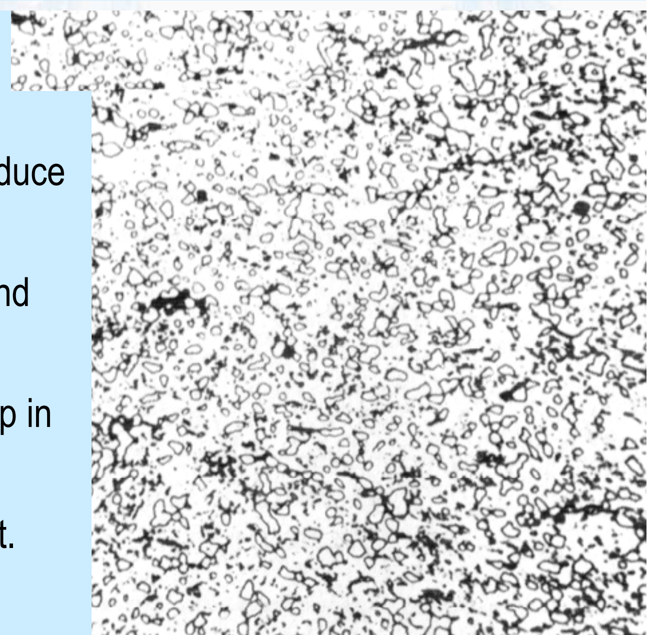
No FCC$\rightarrow$BCC transformation

Most inexpensive stainless steel due to no need for Ni.

General application when corrosion resistance is needed.

Most common: 430 (17 Cr-0.012 C; UTS: 517 MPa, YS: 345 MPa; δ: 25%
446 (25 Cr-0.20 C; UTS: 552 MPa, YS: 345 MPa; δ: 20%

Martensitic Stainless Steels



From 12 to 17% Cr with amounts of carbon (up to 1.1%) necessary to produce martensite

Matrix: martensitic (after quenching and tempering) with carbides.

FCC$\rightarrow$BCT transformation (the α-loop in the phase diagram is increased)

More expensive due to heat treatment.

General application when corrosion resistance needs to be accompanied with very high strength and hardness.

Most common: 440 (17 Cr-0.7+ C); UTS: 1828 MPa, YS: 1690 MPa; δ: 5%

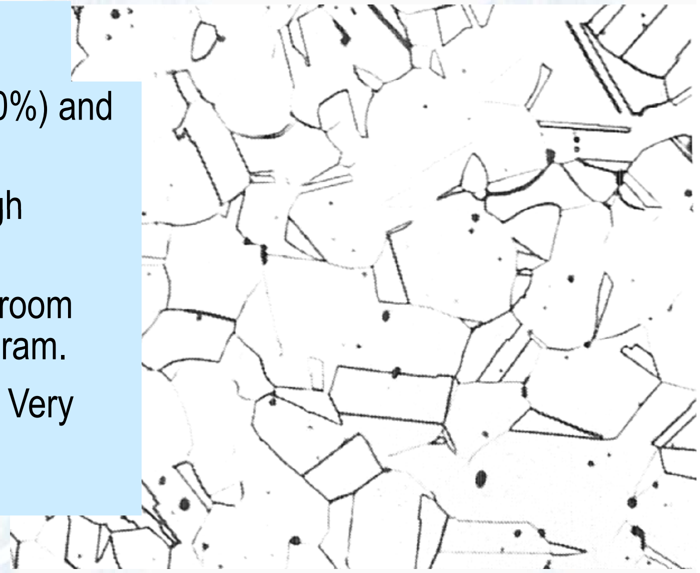
Austenitic Stainless Steels

From 16 to 25% Cr with Ni (7 to 20%) and very little or no carbon

Matrix: austenitic, which allows high formability.

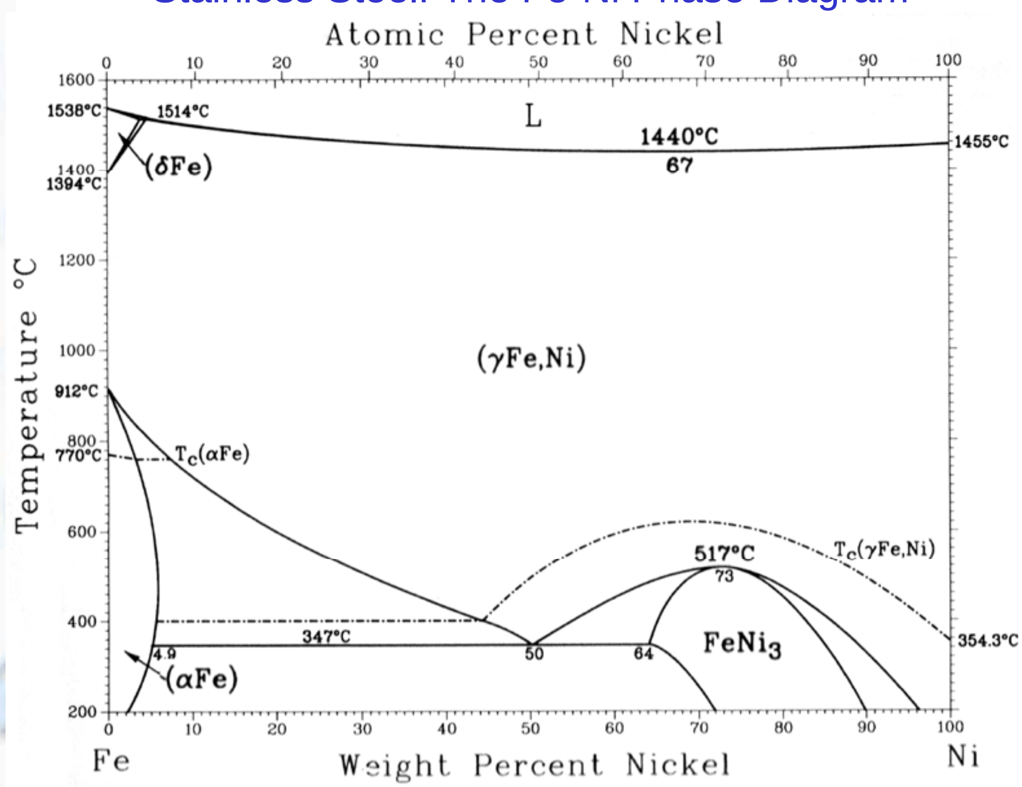
The FCC structure is stabilized at room temperature by Ni. See Fe-Ni diagram.

Most expensive due to Ni content. Very low carbon is needed to avoid intergranular corrosion.

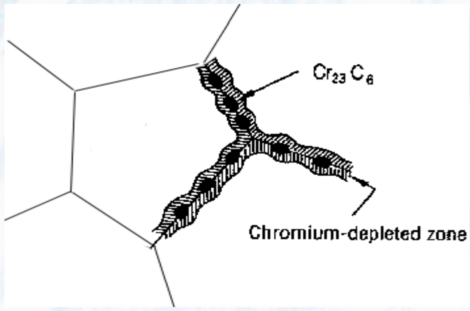


Used when maximum corrosion resistance is needed.
Most common: 304 (19 Cr – 10 Ni; UTS: 580MPa; YS: 290MPa; δ: 55% 316 (18 Cr – 12 Ni; UTS: 500 MPa; YS: 225MPa; δ: 40%

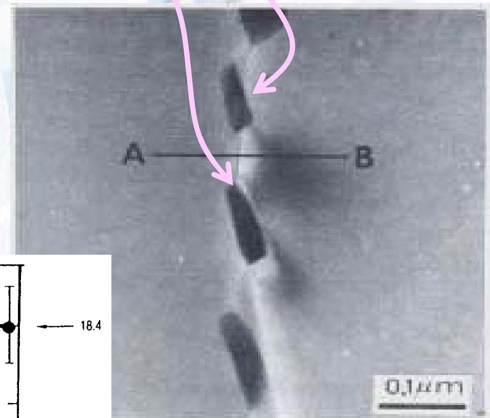
Stainless Steel: The Fe-Ni Phase Diagram



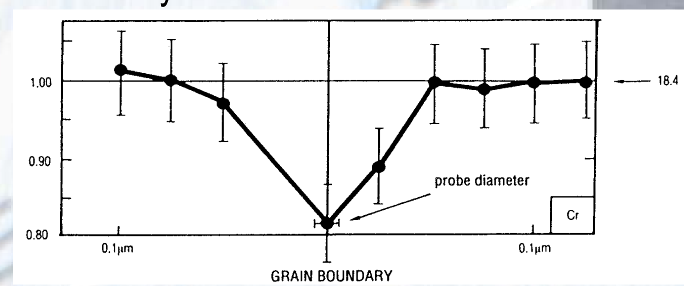
Intergranular Corrosion in Austenitic Stainless Steel



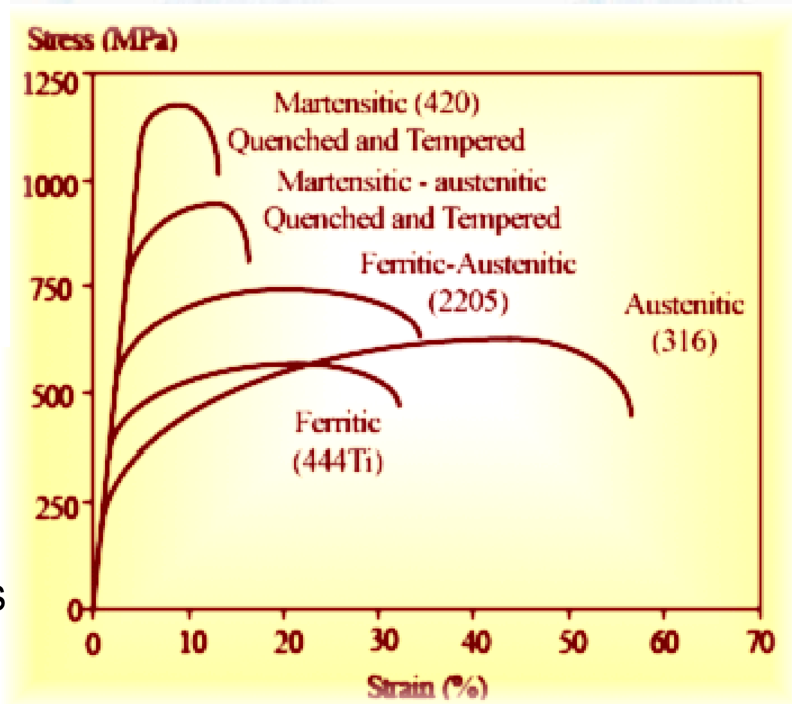
Even small amounts of carbon favor the formation of $M_{23}C_6$



Chromium depletion in the vicinity of a grain boundary in the austenitic steel:



This is an example of tensile test curves obtained for different stainless steels



Extract all the information you need to compare differences in mechanical properties among different types of stainless steels.

Aluminum Alloys

- Main advantage: light weight materials
- Other advantages: high electrical and thermal conductivities, good ductility (with some exceptions), easy to melt and cast, versatile mechanical properties.
- Main disadvantage (for specific potential applications): low melting points.

Classification of Aluminum Alloys

Aluminum Association designation:

- Wrought Alloys
  – 1XXX, 2XXX, 3XXX, 4XXX, 5XXX, 6XXX, 7XXX

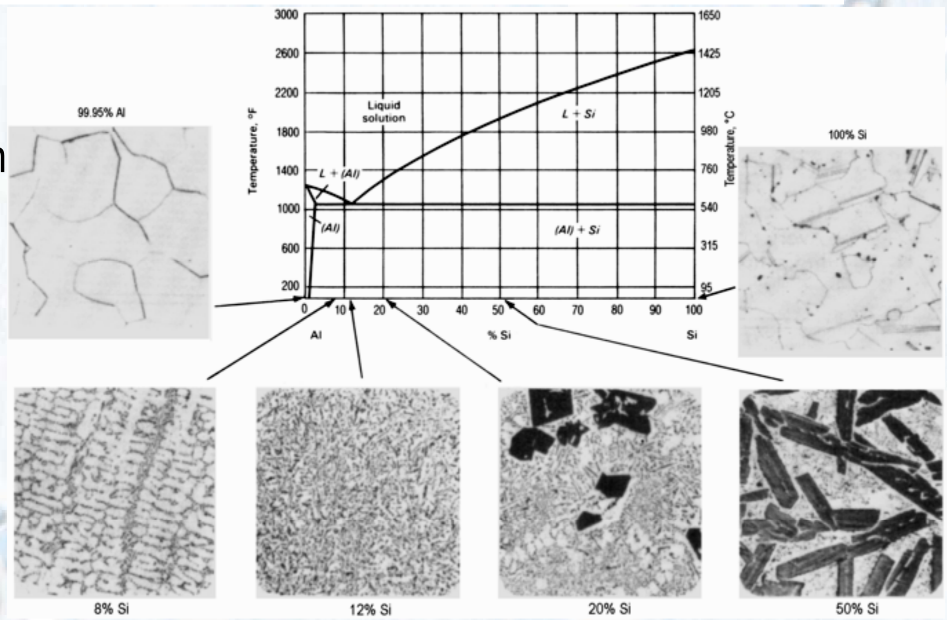


- Cast Alloys
  – 1XX, 2XX, 3XX, 4XX



Most Common Aluminum Cast Alloys

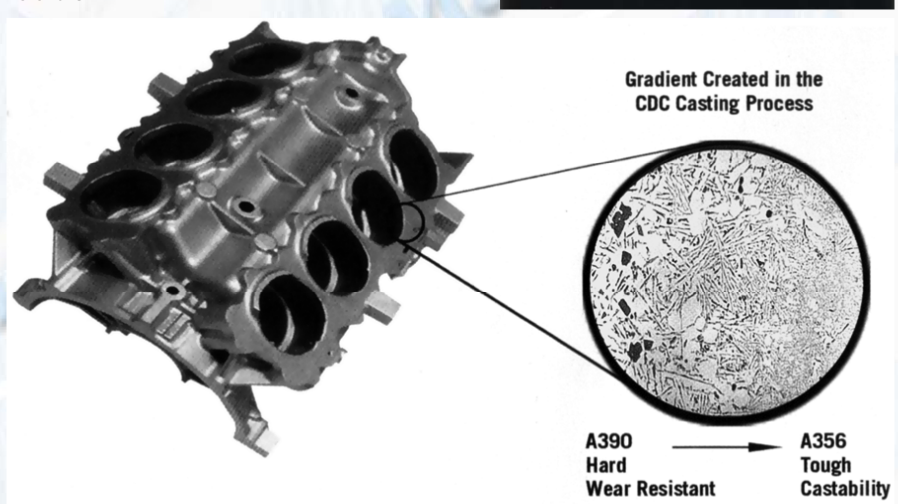
- The most common ones contain silicon (series 3XX and 4XX)
- This is the reason for their good *castability*



Most Common Aluminum Cast Alloys (cont.)

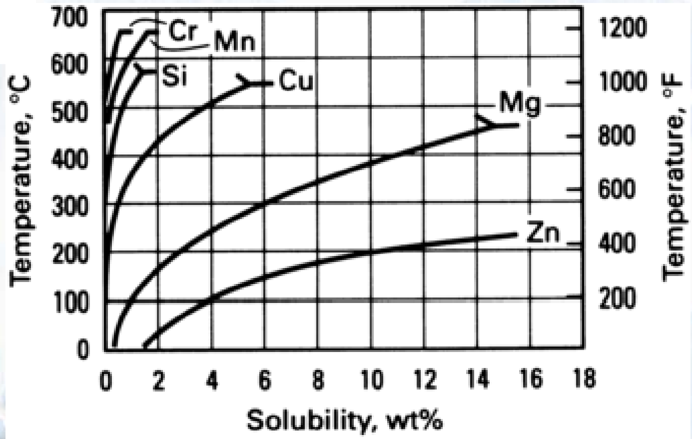
- Used to make parts with complicated forms, some abrasion resistance requirements, low thermal expansion
- In a car engine they are everywhere: block, pistons, cilinder heads

Recently developed functionally-graded aluminum casting: A390→A356



Common Wrought Alloys

- Most of them can be hardened by precipitation hardening (series 20XX and 70XX)
- This requires solubility of the main alloying elements in Al.

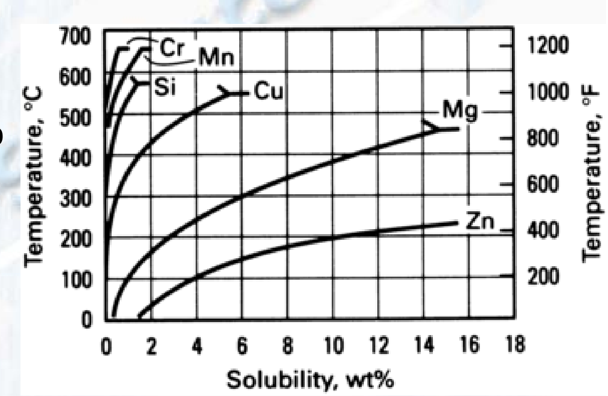


They are used in numerous products:
3XXX (Al-Mn based) in beverage can bodies
5XXX (Al-Mg based) in beverage can taps
6XXX (Al with small Mg and Si) in many extruded products (frames, etc.)
7075 (Al-Zn-Mg based) in main structural components in aircrafts
2014, 2024 (Al-Cu based) in fuselages and wings

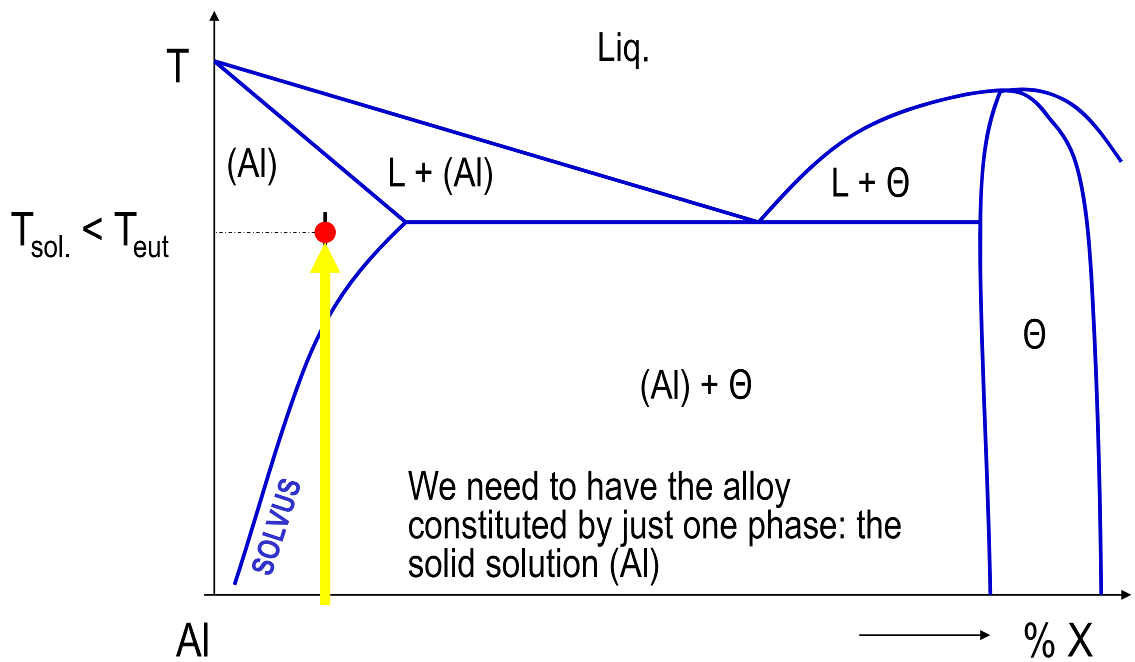
Precipitation Hardening in Al Alloys

We can adjust final hardness or mechanical strength by artificially generating obstacles to dislocation movement.

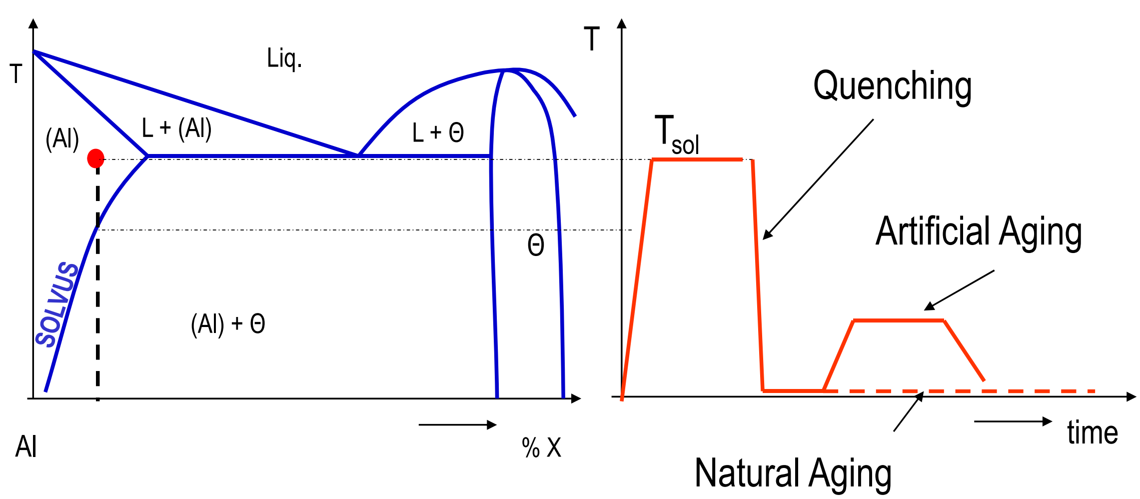
- Solution and precipitation hardening:
  - Two subsequent treatments at two different temperatures.
  - Use the solvus line in the Al-rich side of the phase diagrams to select the solution (solubilizing) temperature.
  - Appearance of new non-equilibrium intermetallic phases.



Solution treatment in Al alloys



Quenching & Aging (Precipitation Hardening)

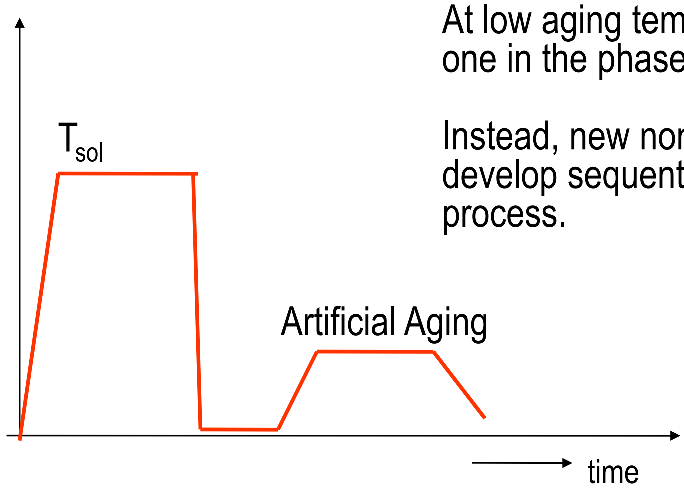


Main quenching goal: retain the (Al) solution at room temperature, but **supersaturated** with atoms of X!

Aging or Precipitation Hardening

At low aging temp. no stable phase (the one in the phase diagram) appears.

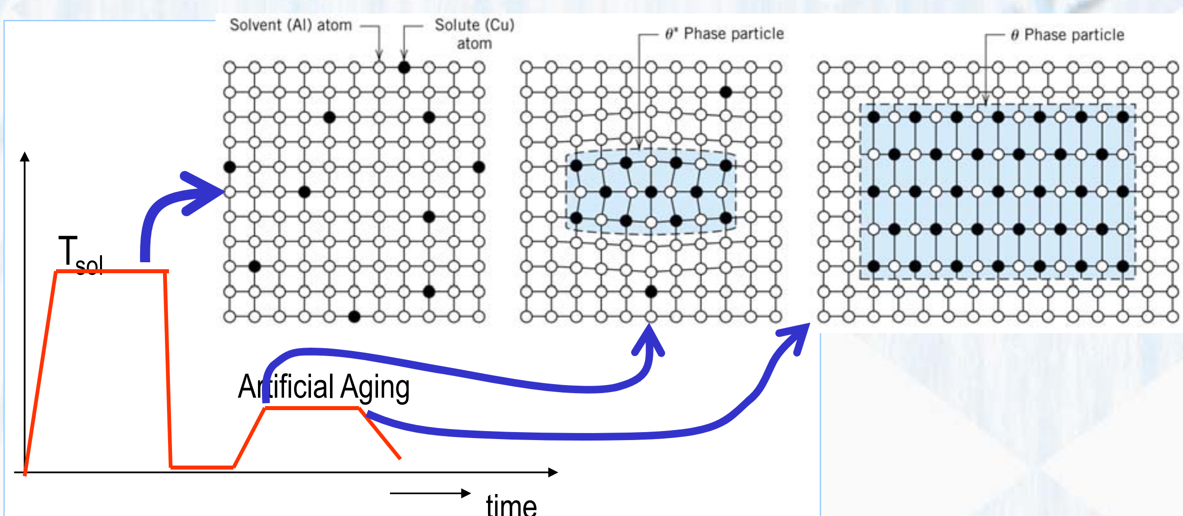
Instead, new non-equilibrium phases develop sequentially during the aging process.



They show up in a sequence: GP zones→Phase1→… →θ

where θ is the stable phase. It appears at longer times: overaged structure

Precipitation Hardening Structures (cont.)

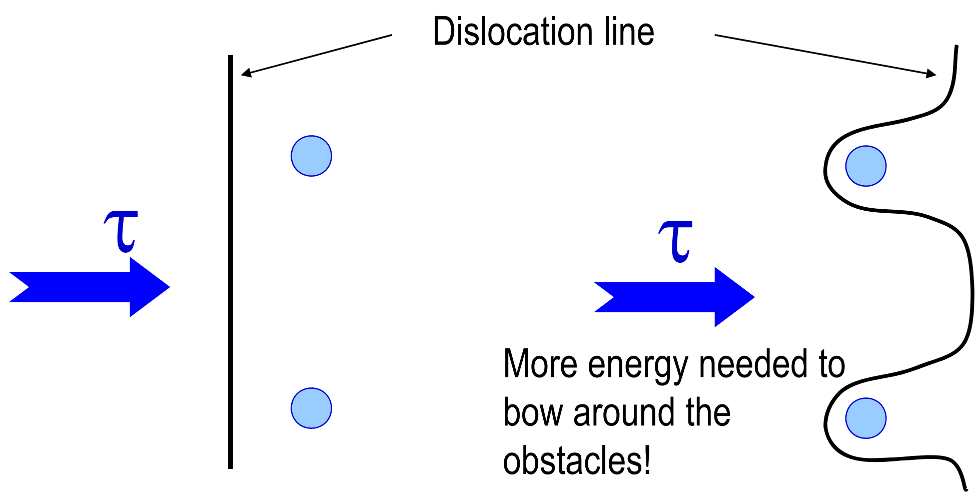


In the Al-Cu system the non-equilibrium phases are called: GP zone →θ''→θ'

Heat treatable Al alloys: Al-Cu, Al-Zn, Al-Mg, Al-Ag, ternary Al-Zn-Mg, etc.

Precipitation Hardening in Al-Cu Alloys

These new phases, GP zones, θ'' and θ' act as obstacles to dislocation motion. Some are more effective than others.



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Precipitation Hardening in Al-Cu Alloys and Their Mechanical Properties

This is the effect of precipitation hardening and the precipitation sequence (GP zones→ θ'' → θ' → θ) on the yield strength and ductility of a AA2014 Al alloy