AS3020: Aerospace Structures

Module 2: Aircraft Materials

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Dept. of Aerospace Engg., IIT-Madras, Chennai

August 9, 2024

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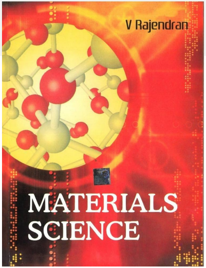
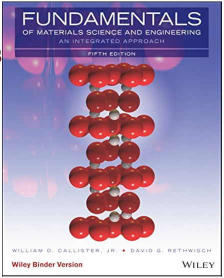
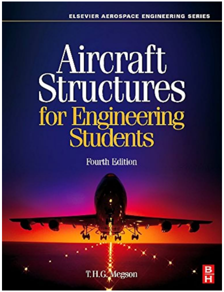


Chapters 2, 9, 11 in Rajendran [1]



Chapters 3, 9, 10 in Jr and Rethwisch [2]



Chapters 11, 15 in Megson [3]

1. Understanding the Stress-Strain Curve

The Uniaxial Tensile Test

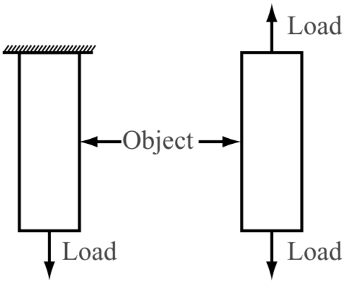


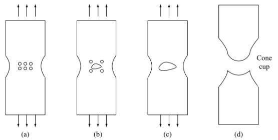
Figure from [1]

1. Understanding the Stress-Strain Curve

Terminology

1. Proportionality Limit;
2. Elastic Limit;
3. Yield Point;
4. Ultimate Strength;
5. Fracture Point;
6. Elongation at Failure;

Ductile Fracture



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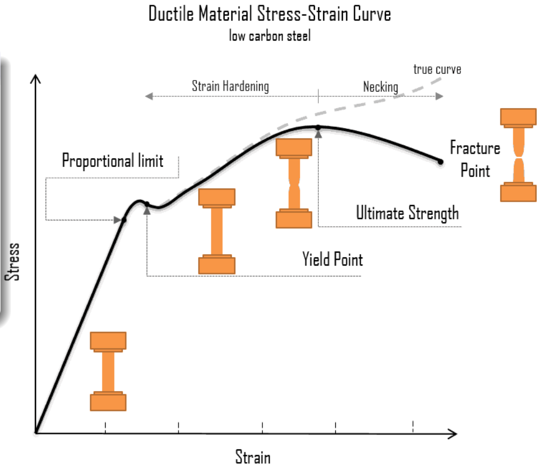

Figure from [4]

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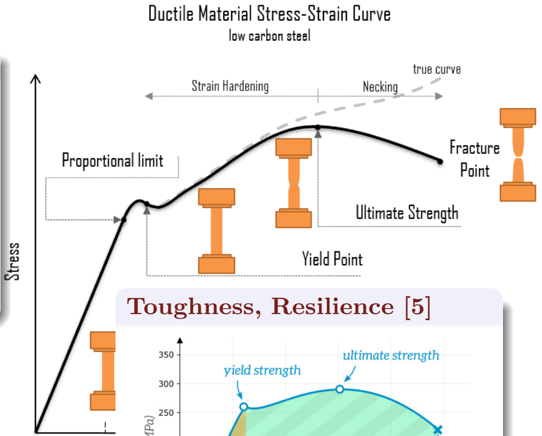


Ductile Fracture

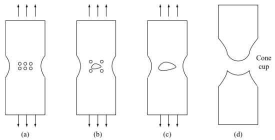
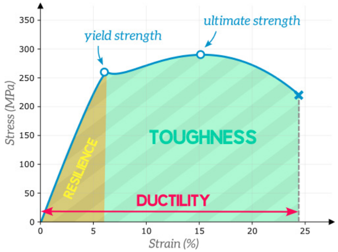


Figure from [1]

Toughness, Resilience [5]



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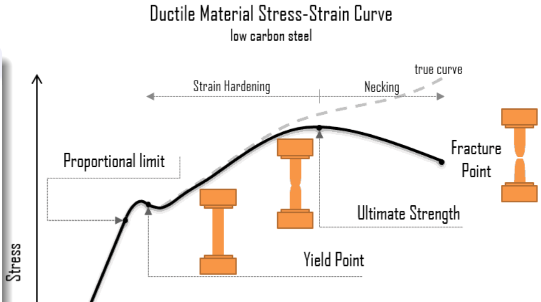

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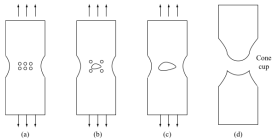
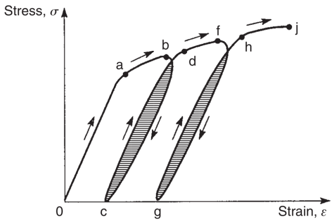


Figure from [1]

Strain Hardening [3]



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Terminology

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Classifications

- Brittle, Ductile
- Non-dissipative: Elastic, Hyper-elastic
- Dissipative: Elastic-perfectly plastic, Bi-linear elastoplastic, etc.

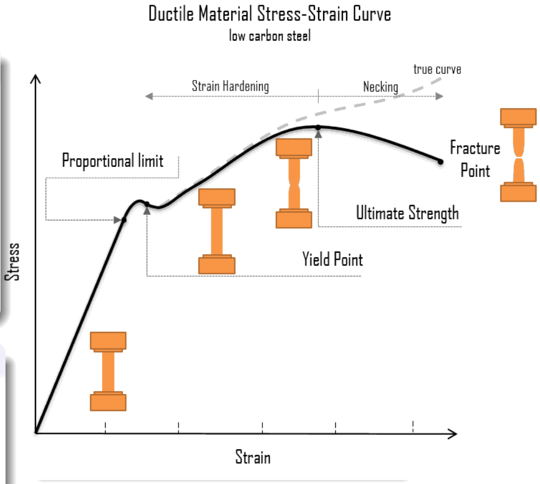

Figure from [4]

1.1. Failure Mechanisms: Fracture

1. Understanding the Stress-Strain Curve

"Griffith Theory" of brittle fracture

- Theoretical fracture stress $\sim \frac{E}{5} - \frac{E}{30}$ (steel $\sim \frac{E}{1000}$)
- Fracture occurs when $E_{strain} = E_{surface}$
- Crack propagates when $\frac{dE_{strain}}{dL} = \frac{dE_{surface}}{dL}$

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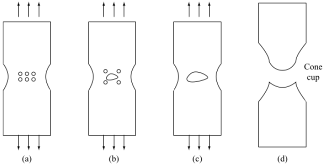

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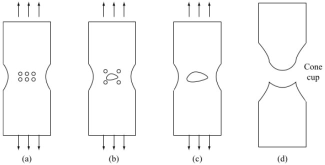


Ductile Fracture [1]

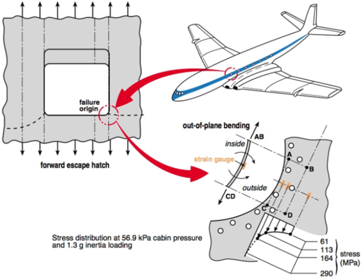
Sr. No	Brittle Fracture	Ductile Fracture
1.	It occurs with no or little plastic deformation.	It occurs with large plastic deformation.
2.	The rate of propagation of the crack is fast.	The rate of propagation of the crack is slow.
3.	It occurs suddenly without any warning.	It occurs slowly.
4.	The fractured surface is flat.	The fractured surface has rough contour and the shape is similar to cup and cone arrangement.
5.	The fractured surface appears shiny.	The fractured surface is dull when viewed with naked eye and the surface has dimpled appearance when viewed with scanning electron microscope.
6.	It occurs where micro crack is larger.	It occurs in localised region where the deformation is larger.

Ductile vs Brittle Fracture [1]

1.1. Failure Mechanisms: Fatigue

1. Understanding the Stress-Strain Curve

..over 90% of mechanical failures are caused because of metal fatigue [6]...



The De Havilland Comet [7]

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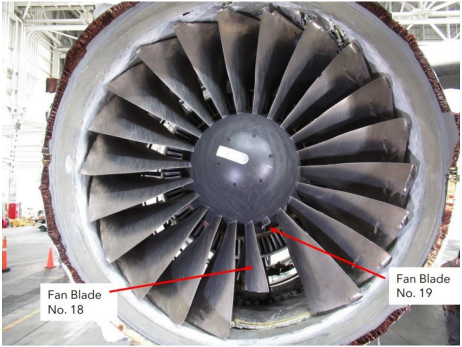
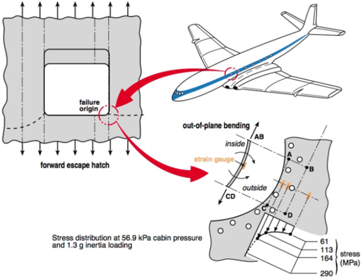


A more recent example (2021 United Airlines Boeing 777) [8]. [video]



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Fatigue Crack Propagation: Beech Marks

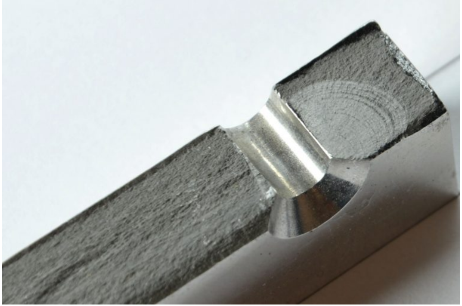
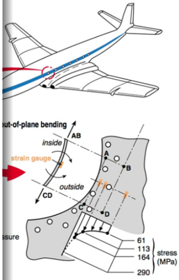


Figure from [9]



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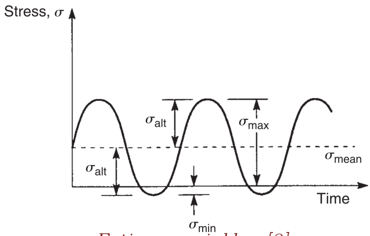
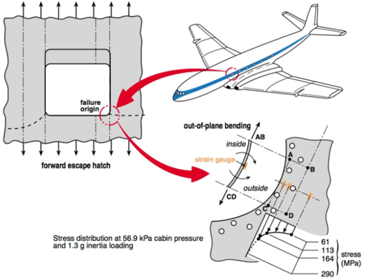


Fatigue variables [3]



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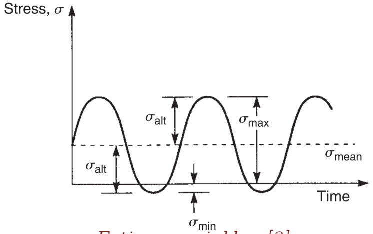

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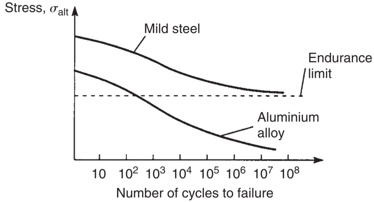
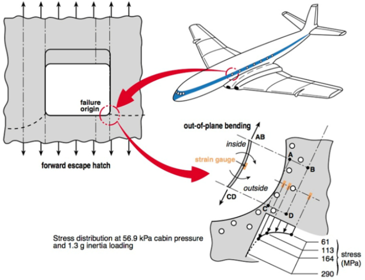


The S-n Diagram [3]

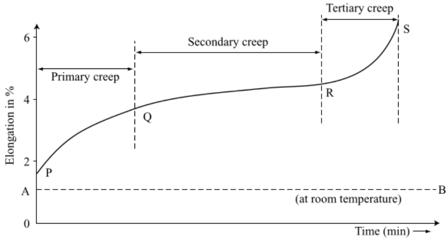


The De Havilland Comet [7]

1.1. Failure Mechanisms: Creep

1. Understanding the Stress-Strain Curve

- Constant stress applied over a long time
- High temperature phenomenon ($> \sim 30 - 45\%$ of melting point)



Creep curve [1]

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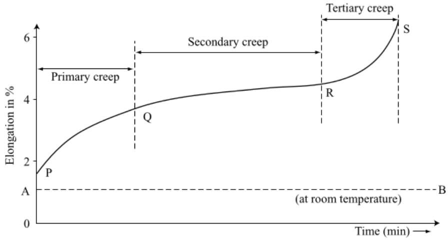
Examples

Zinc Melts at $\sim 420°$ C ($T_{creep} \sim 145°$ C)



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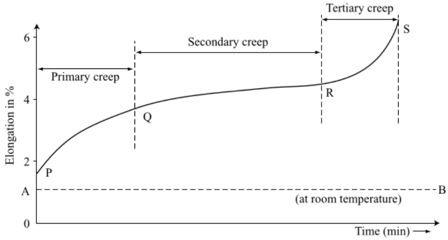

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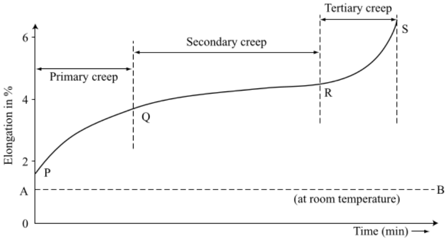

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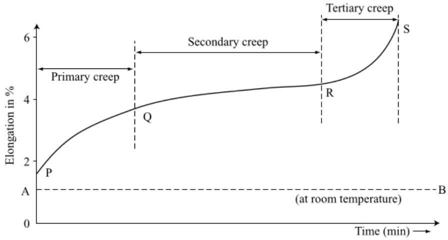

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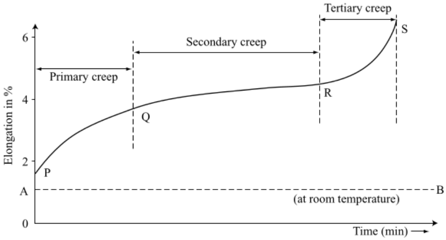
Nickel Melts at $\sim 900°$ C



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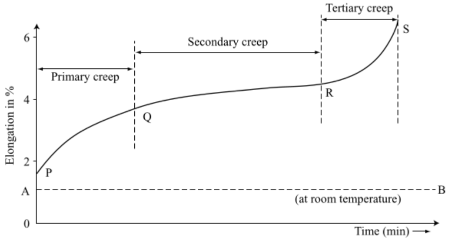

Creep curve [1]

- Fundamentally related to grain dislocation movement
- Single crystal solutions: **Super-Alloys**

2. Materials Used in Aircrafts

2.1. Metallic Alloys

Main Considerations

- Strength-to-weight ratio
- Stiffness
- Toughness
- Fatigue life
- Thermal behavior ("Superalloys")

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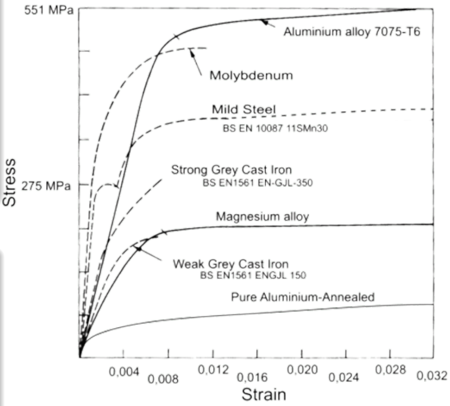
Metallic Alloys/"Solutions"

Fe Alloys C, Ni, Co, Mo, Ti, Mn, Si, S, P (C ↑, Ductility↓)



Stress strain curve of common metals [10]

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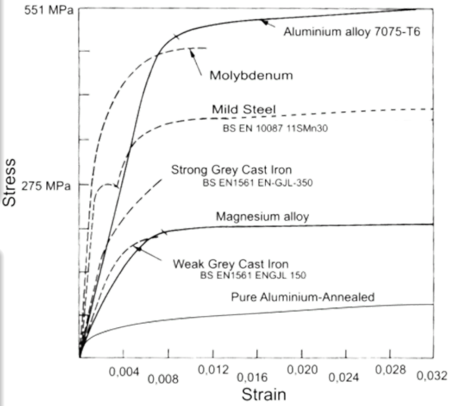

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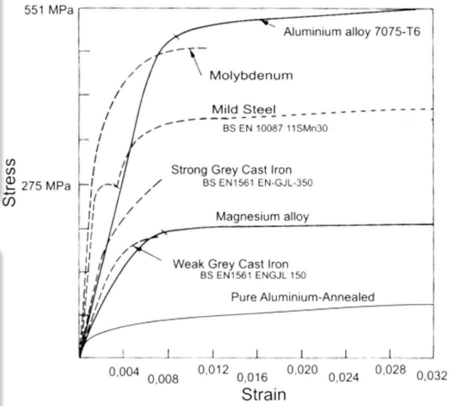
Ti Alloys Al, V



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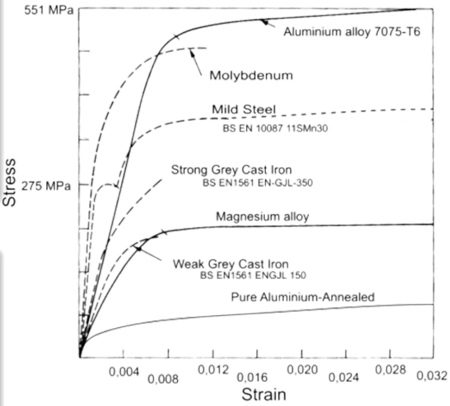

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Metallic All

Fe Alloys

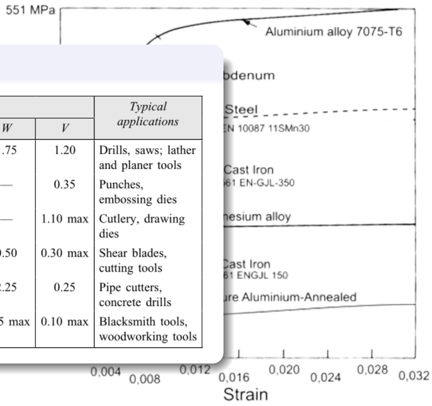
Al Alloys Cu, Mg, Mn, Si, Fe, Zn, Ni, Ti

Ti Alloys Al, V

Ni Superalloys Cr, Al

Steel Alloys [1]

AISI number	*UNS number*	*Composition (wt %)*						*Typical applications*
		C	*Cr*	*Ni*	*Mo*	*W*	*V*	
Ml	T11301	0.85	3.75	0.30 max	8.70	1.75	1.20	Drills, saws; lather and planer tools
A2	T30102	1.00	5.15	0.30 max	1.15	—	0.35	Punches, embossing dies
D2	T30402	1.50	12	0.30 max	0.95	—	1.10 max	Cutlery, drawing dies
O1	T31501	0.95	0.50	0.30 max	—	0.50	0.30 max	Shear blades, cutting tools
S1	T41901	0.50	1.40	0.30 max	0.50 max	2.25	0.25	Pipe cutters, concrete drills
W1	T72301	1.10	0.15 max	0.20 max	0.10 max	0.15 max	0.10 max	Blacksmith tools, woodworking tools



Stress strain curve of common metals [10]

2. Materials Used in Aircrafts

2.1. Metallic Allo

Aluminum Alloys [1]

Sr .No	Alloy	Composition	Properties	Applications
1.	Duralumin	Al = 94% Cu = 4% Mg, Mn, Si, Fe 0.5% each	High tensile strength and high electrical conductance Soft enough for a workable period after it has been quenched. Specific gravity = 2.8 Melting point = 923 K Brinell hardness; Annealed = 60 Age hardened = 100	Sheets, tubes, cables, forgings, rivets, nuts, bolts, etc. Airplanes and other machines, nonmagnetic instruments like surgical and orthapaedic.
2.	Y-Alloy	Al = 92.5% Cu = 4% Ni = 2% Mg = 1.5%	Strength at 573 K is better than aluminium. High strength and hardness at high temperature. Easily cast and hot worked.	Components like piston cylinder heads, crank cases of internal combustion engines and die casting, pump rods, etc.
3.	Hindalium	Cu = 4.5% Si = 0.8% Mn = 0.8% Mg = 0.5% Al = 93.4%	Strong and hard. Cannot be easily scratched. Can take fine finish. Does not absorb much heat and thus saves fuel while cooking. Can be easily cleaned. Do not react with the food acids. Low cost (about one-third of stainless steel).	House bold equipments like pressure vessels, pipes, food and chemical handling storages.
4.	Magnelium	Al = 85 to 95% Cu = 0 to 25% Mg = 1 to 5.5% Ni = 0 to 1.2% Sn = 0 to 3% Fe = 0 to 0.9% Mn = 0 to 0.03% Si = 0.2 to 0.6%	Light weight and high tensile strength annealed state : 200 MNm^{-2} Cold worked state : 280 MNm^{-2} Elongation annealed state : 30% Cold worked state : 7% Alloy is brittle, Castability poor, Machinability good and easily welable.	Gearbox housings, vehicle door handles, luggage racks, coffee-grinder parts and ornamental fixtures.

Main Consi

- Strength
- Stiffness
- Toughne
- Fatigue l
- Thermal

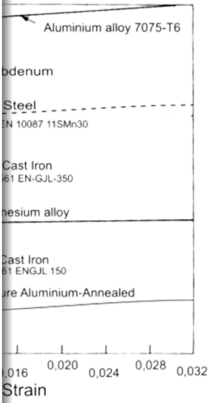
Metallic All

Fe Alloys

Al Alloys

Ti Alloys

Ni Superall



common metals [10]

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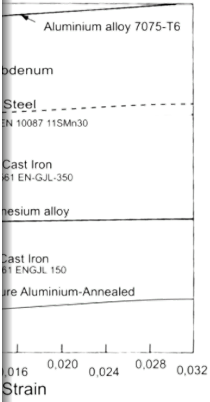
Aluminum Alloys [1]

Sr .No	Alloy	Composition	Properties	Applications
1.	Duralumin	Al = 94% Cu = 4% Mg, Mn, Si, Fe 0.5% each	High tensile strength and high electrical conductance Soft enough for a workable period after it has been quenched. Specific gravity = 2.8 Melting point = 923 K Brinell hardness; Annealed = 60 Age hardened = 100	Sheets, tubes, cables, forgings, rivets, nuts, bolts, etc. Airplanes and other machines, nonmagnetic instruments like surgical and orthapaedic.
2.	Y-Alloy	Al = 92.5% Cu = 4% Ni = 2% Mg = 1.5%	Strength at 573 K is better than aluminium. High strength and hardness at high temperature. ...	Components like piston cylinder heads, crank cases of internal combustion engines ... pump
3.	Hindalium	C... S... M... Mg = 0.5% Al = 93.4%	... Does not absorb much heat and thus saves fuel while cooking. Can be easily cleaned. Do not react with the food acids. Low cost (about one-third of stainless steel).	... pipes, food and chemical handling storages.
4.	Magnelium	Al = 85 to 95% Cu = 0 to 25% Mg = 1 to 5.5% Ni = 0 to 1.2% Sn = 0 to 3% Fe = 0 to 0.9% Mn = 0 to 0.03% Si = 0.2 to 0.6%	Light weight and high tensile strength annealed state : 200 MNm^{-2} Cold worked state : 280 MNm^{-2} Elongation annealed state : 30% Cold worked state : 7% Alloy is brittle, Castability poor, Machinability good and easily welable.	Gearbox housings, vehicle door handles, luggage racks, coffee-grinder parts and ornamental fixtures.

Necessary Reading

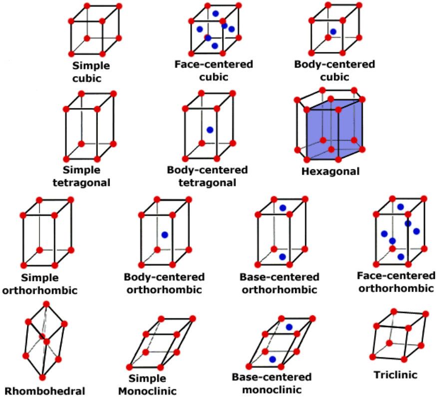
Pages 353-359 in Megson [3].



...common metals [10]

3. Introduction to Material Science

3.1. Introduction to Material Science



Types of crystal structures in metals [11]

3. Introduction to Material Science

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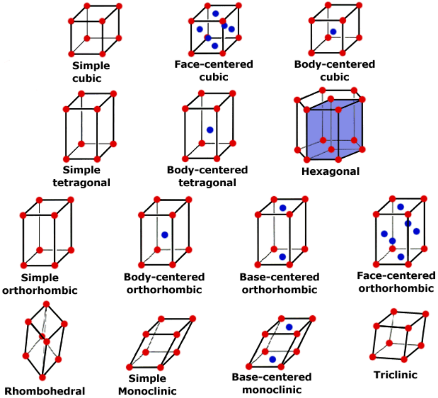

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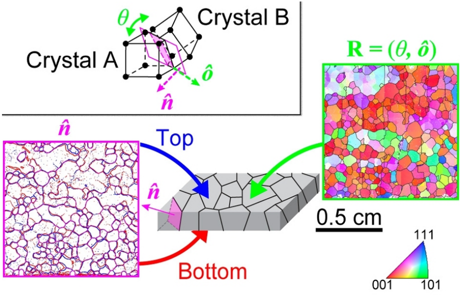

Crystal and Grain Structures [12].
"Polycrystallinity"

3. Introduction to Material Science

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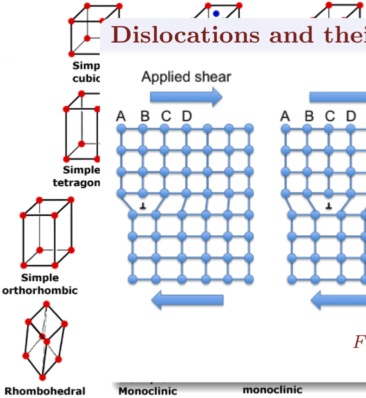


Dislocations and their "motion" under load

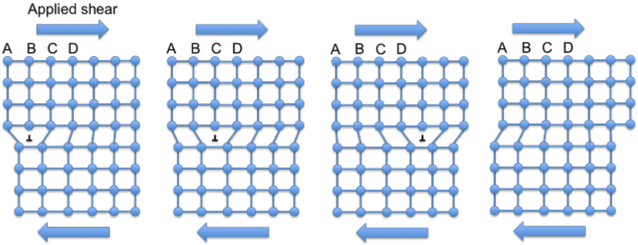
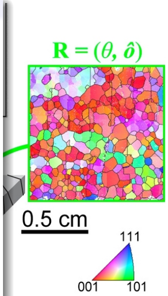


Figure from [11]



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Types of crystal structures in metals [11]

3.2. Phase Diagrams

3. Introduction to Material Science

Mechanical properties are a direct consequence of microstructures, which are direct consequences of thermal histories.

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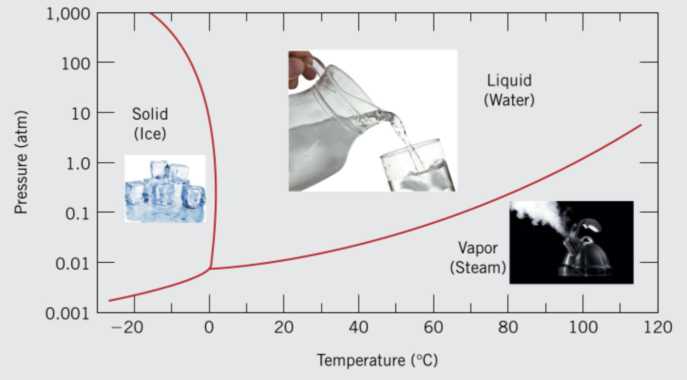
What is a phase diagram? [2]



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3. Introduction to Material Science

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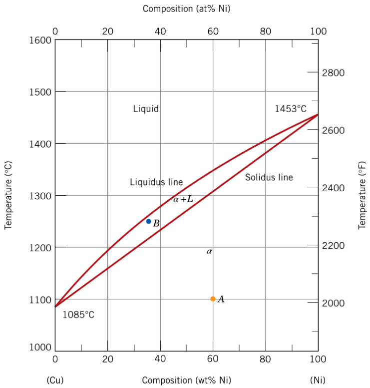
The Copper-Nickel Phase Diagram [2]



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3. Introduction to Material Science

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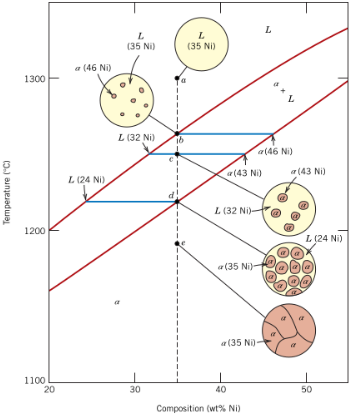
Equilibrium Cooling [2]



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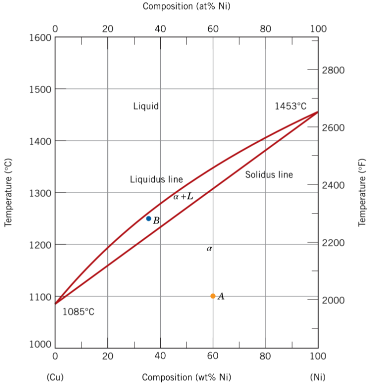
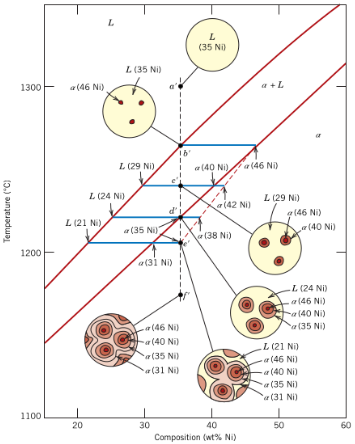


3.2. Phase Diagrams

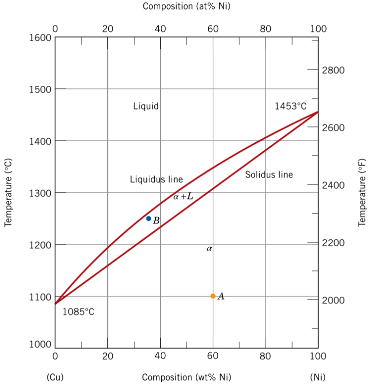
3. Introduction to Material Science

Mechanical properties are a direct consequence of microstructures, which are direct consequences of thermal histories.

Non-Equilibrium Cooling [2]



The Copper-Nickel Phase Diagram [2]



3.2. Phase Diagrams

3. Introduction to Material Science

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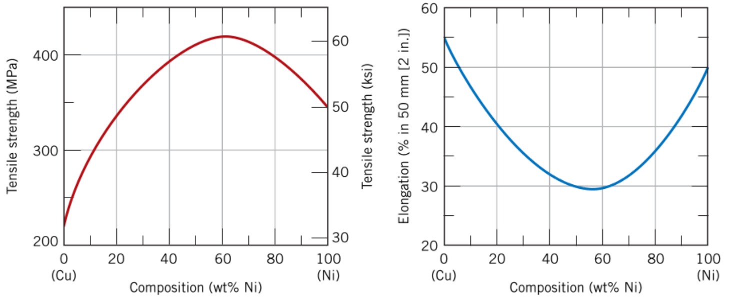
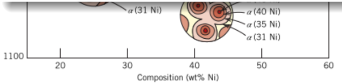
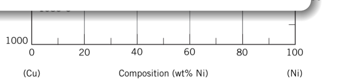
Non-Equilibrium Cooling [2]

The Copper-Nickel Phase

Mechanical Ramifications [2]



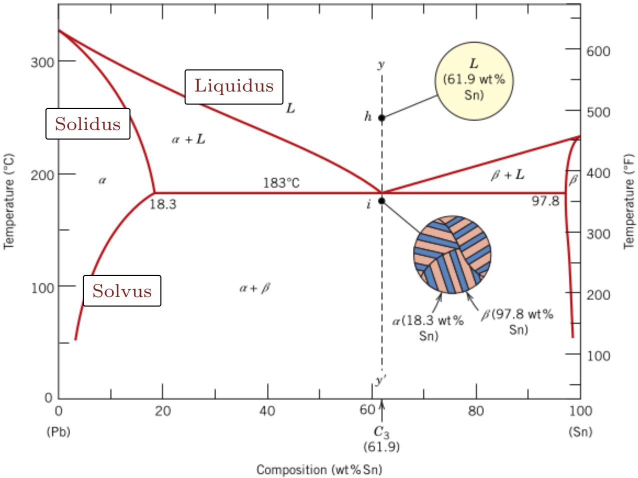




3.2. Phase Diagrams: Eutectic Systems

3. Introduction to Material Science

The Lead-Tin System [2]



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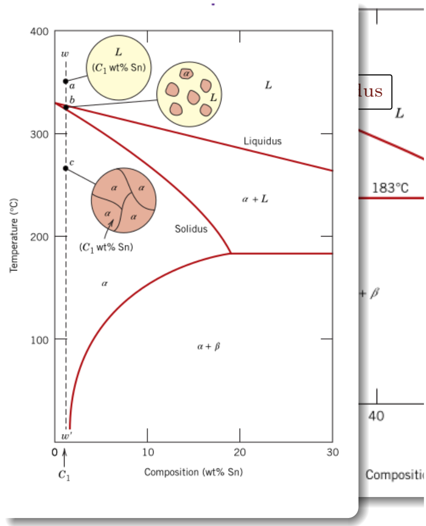

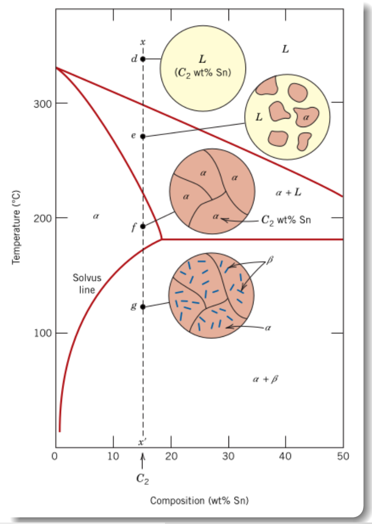

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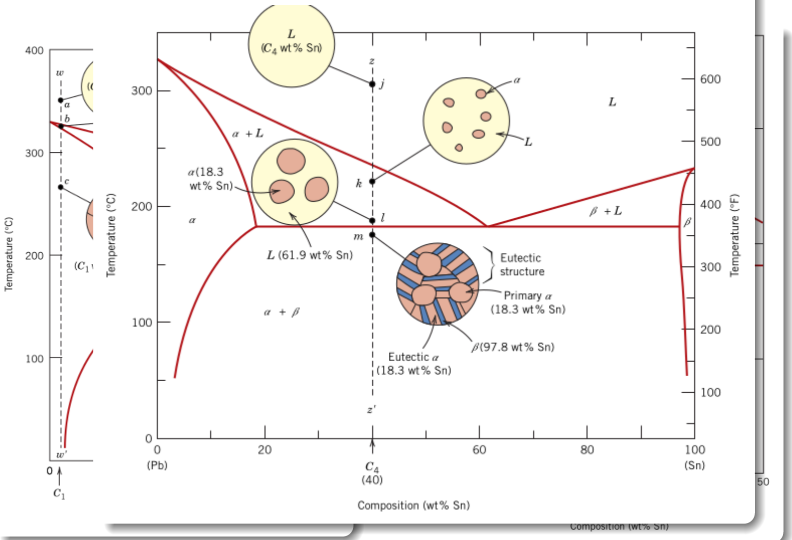

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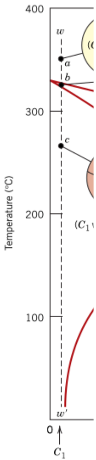
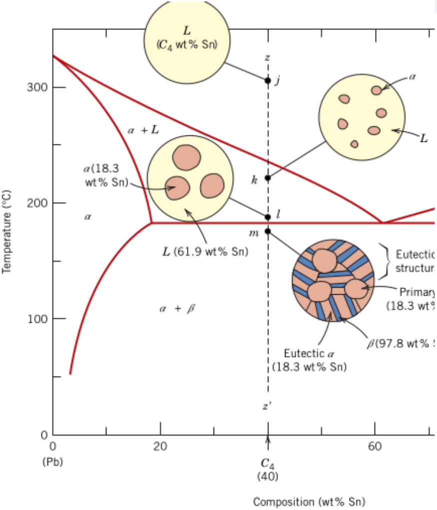
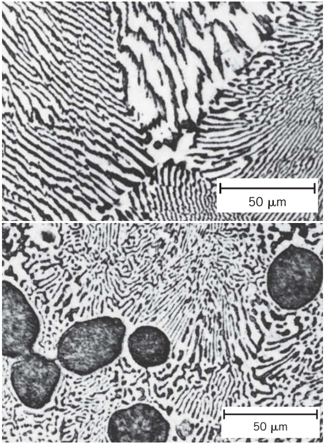


The Lead-Tin System [2]



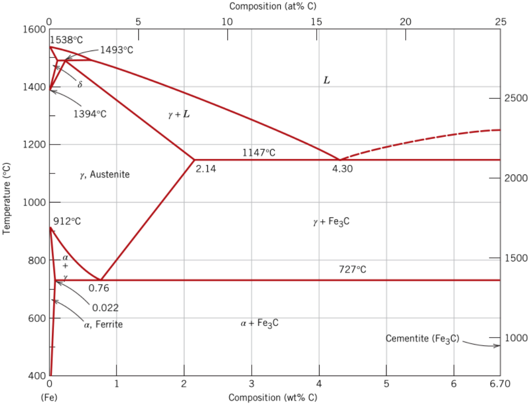
Some Pictures [2]

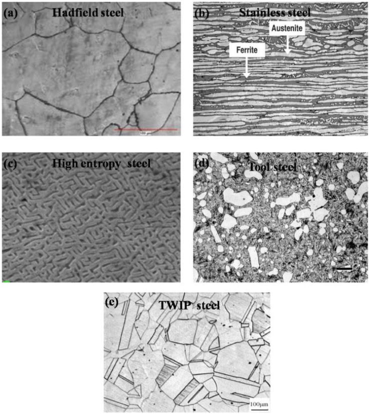


3.2. Phase Diagrams

3. Introduction to Material Science

The Iron Carbon System [2]





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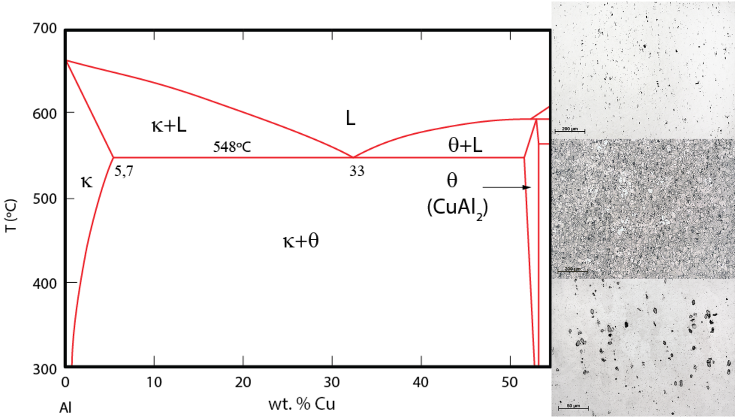
3. Introduction to Material Science

The Al-Cu-Mg System (2024 AA) [13]



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[10] *What Is a Stress-Strain Curve? | Documentation.* URL: https://www.simscale.com/docs/simwiki/fea-finite-element-analysis/what-is-a-stress-strain-curve/ (visited on 08/09/2024) (cit. on pp. 23–30).

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