Exercise walk-through

4.3 Metals and alloys

University Mechanical Engineering

Bonding sets the property family

metallic
steel, aluminium
ductile, tough, conducts heat and charge

covalent / ionic
alumina, silicon carbide
stiff, hard, brittle, insulating, heat-resistant

polymer chains
nylon, epoxy
light, compliant, viscoelastic, creeps

> Polymer chains give light, viscoelastic solids

Selection in action: one method, two answers

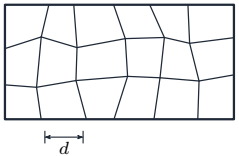
1. **Rank** $\sqrt{E}/\rho$: CFRP 7.37 wins stiffness-per-mass at 2.4× aluminium.
2. **Eliminate** Plain nylon fails the T_g constraint; ceramics fail the survival probability at these loads.
3. **Split** The mount ships quenched-and-tempered steel (620 MPa, 16%); the carry-handle ships CFRP.

The project sheet, reproducible

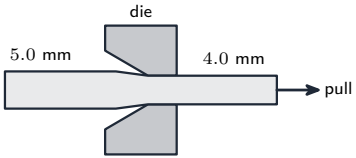
1. **Structure** BCC 0.6802, FCC 0.7405; Hall-Petch 183.6 $\rightarrow$ 262.3 MPa for 50 $\rightarrow$ 10 µm.
2. **Certificate** Rod 191.0 MPa: 0.477 vs 1.364 mm; true ln 1.2 $=$ 0.1823; **toughness** 92.8 MJ/m^3.
3. **Choice** Routes 280/24, 260/26, 620/16, 950/8; Chvorinov 22.2 vs 50.0 s; Basquin 303.1 at 10^5, 250 at 10^6; Goodman 175.0; index 7.37 / 3.10 / 1.80 / 1.23 - steel mount, CFRP handle.

Exercises 2.1·2.2

2.1 For the steel in worked example 1, find the grain size needed for $\sigma_y = 250$ MPa. [3]

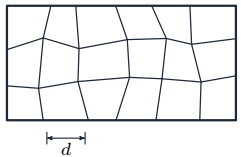


2.2 Copper wire is drawn from 5.0 mm to 4.0 mm diameter. Find the percent cold work, and say how the strength and the ductility change. [2]



Exercises 2.1·2.2

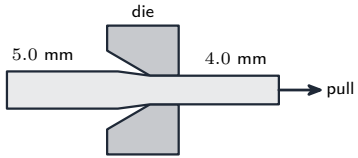
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2.1

$kd^{-1/2} = 180$ MPa; $d^{-1/2} = 243$ m$^{-1/2}$; $d = \mathbf{17}\ \boldsymbol{\mu}\mathbf{m}$

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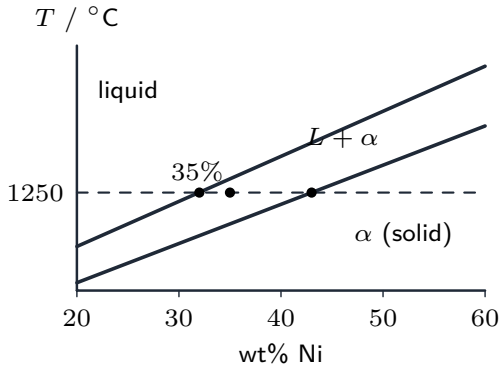
2.2

$$\%\text{CW} = \frac{25 - 16}{25} = \mathbf{36}\%$$; strength and hardness rise, ductility falls

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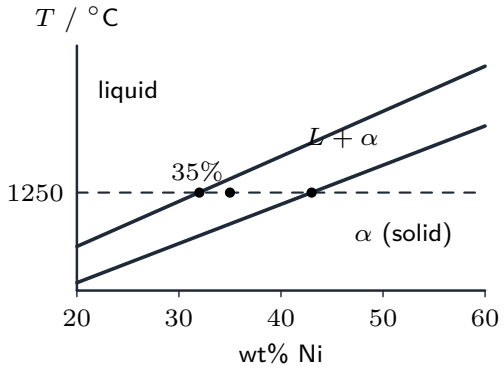
Exercise 2.3

2.3 A copper–nickel alloy with 35 wt% Ni is held at 1250°C. The tie line meets the liquidus at 32% Ni and the solidus at 43% Ni. Find the phases, their compositions and their amounts. [3]



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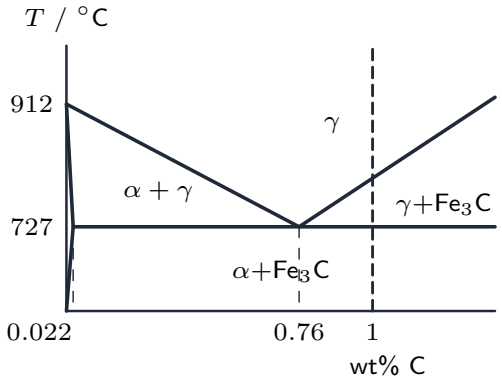
2.3

liquid with 32% Ni and solid α with 43% Ni; $W_L = \dfrac{43-35}{43-32} = \mathbf{0.73}$, $W_\alpha = \mathbf{0.27}$

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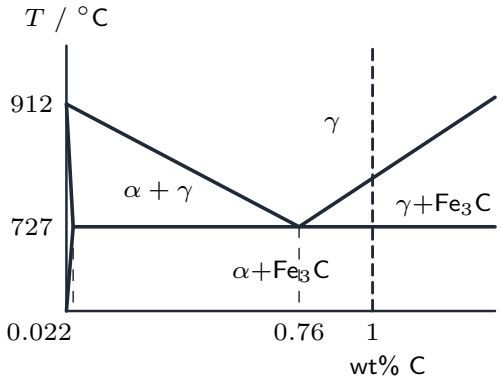
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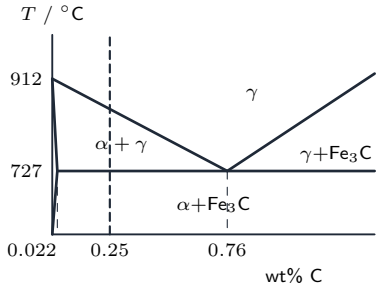
2.4

lever rule between 0.76% and 6.70%: $W_{Fe_3C} = \dfrac{1.0 - 0.76}{6.70 - 0.76} = \mathbf{0.040}$; it forms on the old austenite grain boundaries, around the pearlite, and makes the steel brittle

Exercise 3.1

3.1 A 0.25 wt% C steel is cooled slowly to just below 727°C.

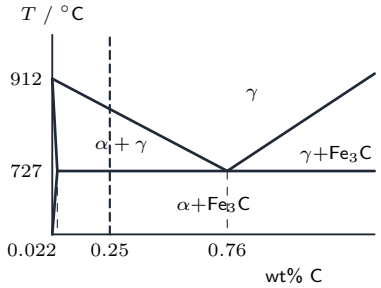
Find the fractions of proeutectoid ferrite and pearlite, and the total fractions of ferrite and cementite. Say whether this steel suits a car body panel or a file. [4]



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3.1

$W_P = \dfrac{0.25 - 0.022}{0.738} = \mathbf{0.31}$, proeutectoid ferrite $\mathbf{0.69}$

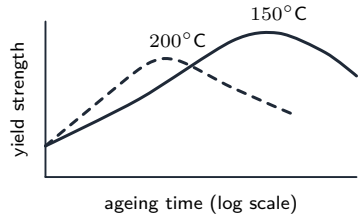
total $Fe_3C = \dfrac{0.25 - 0.022}{6.70 - 0.022} = \mathbf{0.034}$, total ferrite $\mathbf{0.966}$

mostly soft ferrite: ductile and easy to form, so a **car body panel** (a file needs a high-carbon hardened steel)

Exercise 3.2

3.2 The figure shows how the yield strength of an Al–Cu alloy changes with ageing time at 150°C and at 200°C.

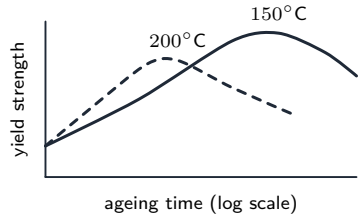
Describe the three steps of precipitation hardening. Explain why the strength falls after the peak, and why the peak is lower at 200°C. [4]



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3.2

solution treat (dissolve Cu), quench (trap it in a supersaturated solid solution), age (fine precipitates form)

fine, closely spaced precipitates pin dislocations best; after the peak they grow and spread apart, so dislocations bow round them: **overageing**

at 200°C diffusion is faster, so fewer, coarser precipitates form and the peak is earlier and lower

Exercise 3.3 (a)

3.3 A plain steel bolt needs $\sigma_y \geq 400$ MPa and an elongation of at least 14%. For this steel, $\sigma_0 = 70$ MPa and $k = 0.74$ MPa $\mathrm{m}^{1/2}$, and its usual grain size is 20 μm. Cold drawing gives $\sigma_y = 250 + 8.0 \times \%\mathrm{CW}$ MPa and an elongation of $30 - 0.80 \times \%\mathrm{CW}$ percent.

(a) Find σ_y at the usual grain size, and the grain size needed for 400 MPa by grain refinement alone. [2]

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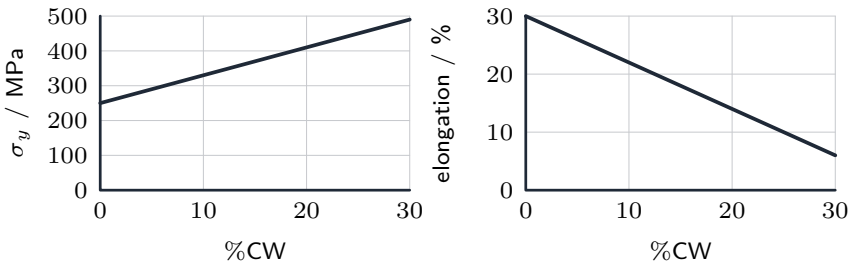
(a) Find σ_y at the usual grain size, and the grain size needed for 400 MPa by grain refinement alone. [2]

(a) $\sigma_y = 70 + 0.74/\sqrt{2.0 \times 10^{-5}} = \mathbf{235\ MPa}$; $d^{-1/2} = 446$, $d = \mathbf{5}\ \mu\mathbf{m}$, too fine for normal rolling

Exercise 3.3 (b)

3.3 A plain steel bolt needs $\sigma_y \geq 400$ MPa and an elongation of at least 14%. For this steel, $\sigma_0 = 70$ MPa and $k = 0.74$ MPa $\text{m}^{1/2}$, and its usual grain size is 20 μm. Cold drawing gives $\sigma_y = 250 + 8.0 \times \%\text{CW}$ MPa and an elongation of $30 - 0.80 \times \%\text{CW}$ percent.

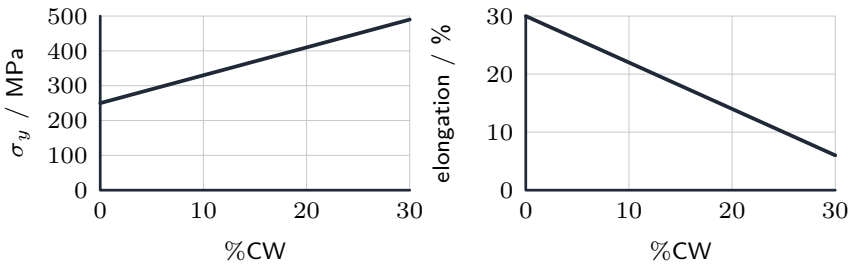
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(b) Find the range of cold work that meets both requirements. [3]



(b) $250 + 8.0\,\mathrm{CW} \geq 400$: $\mathrm{CW} \geq \mathbf{18.75}\%$; $30 - 0.80\,\mathrm{CW} \geq 14$: $\mathrm{CW} \leq \mathbf{20}\%$; the window is only 1.25% wide

Exercise 3.3 (c)

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(c) $d_0 = \dfrac{12.0}{\sqrt{1 - 0.194}} = \mathbf{13.4\ mm}$; not robust: a small error in the drawing takes the bolt out of the window; use a medium-carbon steel, quenched and tempered