Exercise for the Lecture on Materials Science

Prof. Peter Müller-Buschbaum, Lea Westphal, Ziyan Zhang, Doan Duy Ky Le

Exercise Sheet 5

Discussion on May 28, 2025

Task 1: Fracture Types

Below are four images of fracture surfaces of metallic materials after tensile testing. Your task is to correctly assign each image to the appropriate fracture type and analyze the behavior.

Image A

Image B

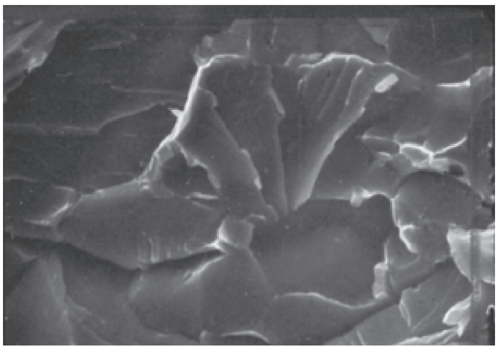

Image C

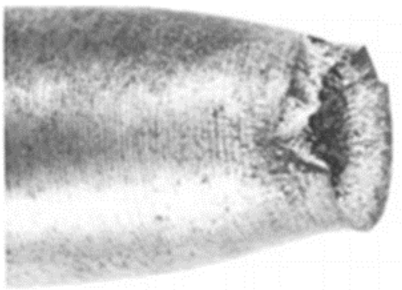

Image D

Fig. 1: Fracture surfaces of metallic materials after tensile testing [1, 2]

Answer the following questions for each fracture type:

1. What mechanisms lead to crack initiation and propagation? Address dislocation movement, energy dissipation, and the stress state.
2. Discuss what the respective fracture behavior implies for the component's safety and damage tolerance.

Task 2: Failure Analysis

You are a materials consultant in an engineering office for failure analysis and quality assurance. You are regularly tasked with evaluating failure cases and component tests based on fracture mechanics. As part of an internal case study, analyze the following three cases.

a) Case 1: Brittle plastic housing

A thin-walled housing component made of polystyrene (PS) was submitted for analysis. It is used in a household appliance and is exposed to a uniform mechanical tensile load of approximately 1.4 MPa. The elastic modulus of the material is 3.2 GPa and the measured surface energy is $0.4\,\mathrm{J\,m^{-2}}$.

Use the Griffith criterion to calculate the maximum crack length that can still be considered non-critical.

b) Case 2: Crack in an aluminum structure

A wing component of an unmanned aircraft failed during a load test. A crack approximately 2.2 mm long was discovered in the interior of the material. The material is a high-strength aluminum alloy with a fracture toughness of $38\,\mathrm{MPa}\sqrt{\mathrm{m}}$. The component failed at a critical stress of 360 MPa.

For a new design, a larger crack of 4.5 mm is assumed. Determine the maximum allowable operating stress for which the component can still be considered safe.

c) Case 3: Allowable crack length in production

A newly developed polymer component for a medical device is manufactured using injection molding. During use, the component is typically exposed to a stress of 4.2 MPa. From a quality assurance standpoint, cracks smaller than 0.4 mm cannot be reliably detected.

The polymer has a specified fracture toughness of $2.1\,\mathrm{MPa}\sqrt{\mathrm{m}}$. Assess whether such a crack is safely tolerable under the given load or if failure is likely.

Task 3: Binary Phase Diagrams

Nickel–copper alloys are a classic example of binary isomorphous systems and are used, for example, in piping systems. The following phase diagram describes the thermodynamic behavior of this alloy system.

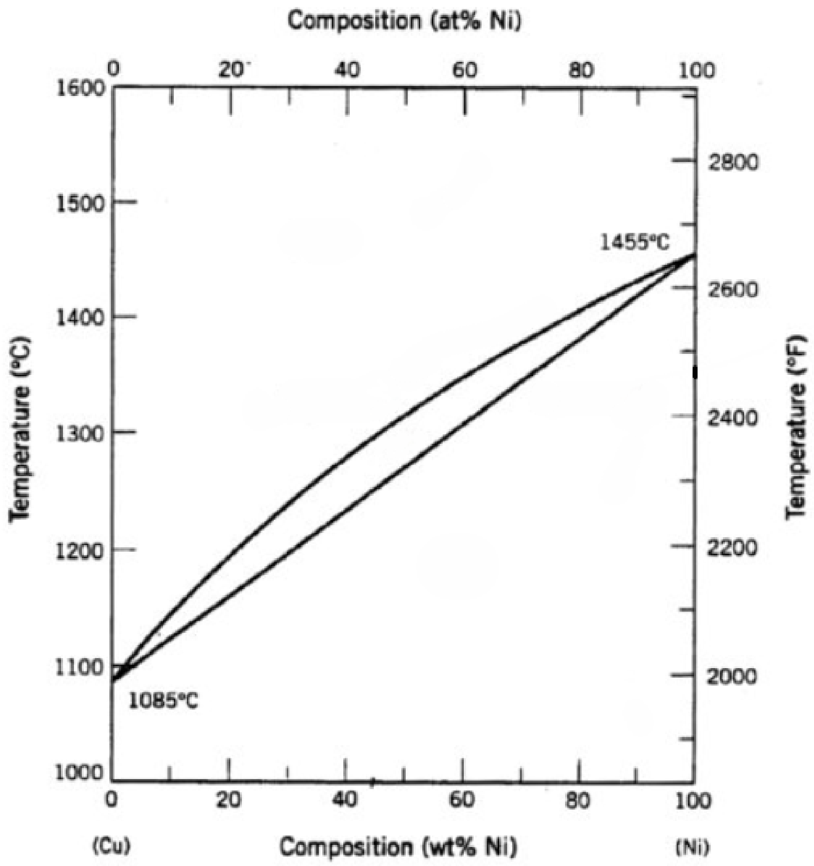

Fig. 2: Phase diagram of the binary isomorphous Cu–Ni system [3]

1. Identify the following regions in the diagram:
   - single-phase liquid (L),
   - single-phase solid (α-solid solution),
   - two-phase region (L + α),
   - liquidus line,
   - solidus line.
2. Consider a Cu–Ni alloy with 30 mass-% nickel. Draw the composition line in the diagram.
3. Determine the temperature range in which this alloy solidifies. Give the temperatures where the composition line intersects the liquidus and solidus lines.

4. Determine the temperature at which equal amounts (by volume or mass) of solid phase (α) and liquid (L) are present.

5. For the temperature found in Task 3.4, determine the nickel concentration

   - in the liquid phase L,
   - in the solid α-phase.

   Read the values at the intersections of the tie line with the liquidus and solidus lines (in mass-% Ni).

Task 4: Eutectic Phase Diagrams

Consider the theoretical eutectic binary system A–B as shown in Fig. 3. The α-phase is A-rich, and the β-phase is B-rich. A composition P is located in the two-phase region $\alpha + \beta$ at a given temperature T.

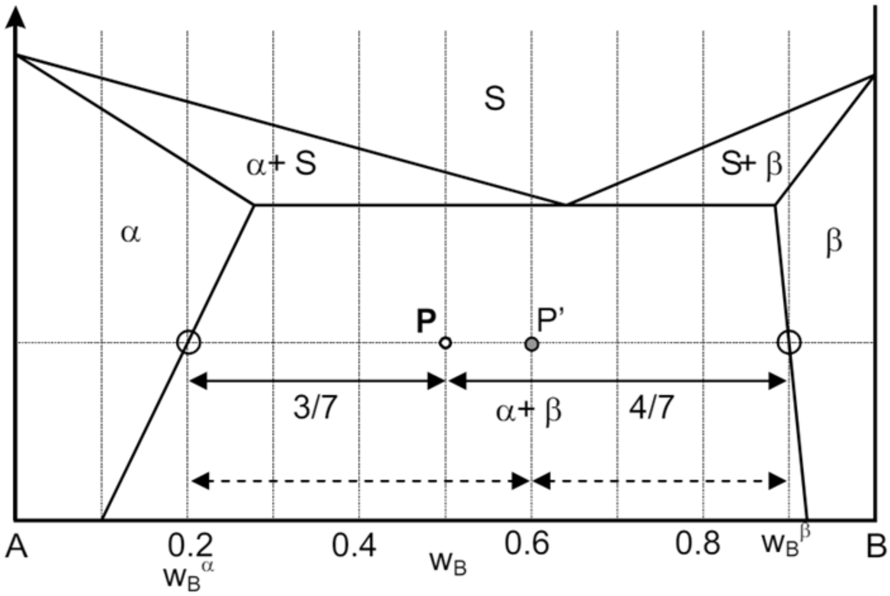

Fig. 3: Theoretical eutectic phase diagram

1. Determine the mass fractions of the α- and β-phases at point P. Use the lever rule.

2. Determine the compositions of the two phases at point P.

3. How do your answers change if point P moves to the right in the diagram (i.e., the alloy has a higher B content)?

4. What is the difference between the solidification of a eutectic alloy at the eutectic point and the solidification of a non-eutectic composition in the two-phase region ($L + \alpha$ or $L + \beta$)?

Task 5: Determining Phase Boundary Compositions

At approximately 150 °C, a Pb–Sn alloy is located in the two-phase region $\alpha + \beta$. The α-phase is Sn-rich, and the β-phase is Pb-rich. For two different alloys, the mass fractions of the two phases have been determined by metallographic analysis.

Table 1: Mass fractions of phases in two Pb–Sn alloys at 150 °C [4, 5]

Alloy composition	Mass fraction α-phase	Mass fraction β-phase
15 wt.-% Sn / 85 wt.-% Pb	0.20	0.80
60 wt.-% Sn / 40 wt.-% Pb	0.78	0.22

Based on the compositions listed in Table 1, determine the phase boundary compositions for both the α- and β-phases at this temperature.

References

[1] D. R. Askeland, P. P. Fulay, and W. J. Wright, *The Science and Engineering of Materials*, 6th ed. Cengage Learning, 2010.

[2] D. Askeland, F. Haddleton, and P. Green, *Science and Engineering of Materials*. Boston: Springer US, 2013.

[3] Y. Zhang, "microstructures and properties of high entropy alloys," *Progress in Materials Science*, vol. 61, pp. 1–93, 04 2014.

[4] A. International, *Binary Alloy Phase Diagrams*. ASM Handbook, 1990, vol. 1.

[5] W. D. Callister and D. G. Rethwisch, *Materialwissenschaften und Werkstofftechnik*. Wiley-VCH, 2020.