Materials Lab Questions
HSLU, Semester 3

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Contents

1 Basics and Crystal Structure

1.1 How are Young's modulus, binding energy, and the coefficient of thermal expansion qualitatively related?

1.2 What is the plastic deformation of metals at room temperature based on?

1.3 In dishwashers, the side walls often consist of stainless ferritic chromium steel (body-centered cubic, BCC). For the bottom, which is subjected to very large plastic deformations during manufacturing, the choice usually falls on a stainless austenitic chromium-nickel steel (face-centered cubic, FCC). Explain the material choice for the tub bottom; please argue using the crystal structure.

1.4 Why are FCC and BCC metals easier to plastically deform than the hexagonal close-packed (HCP) titanium?

1.5 The strength of metals can be increased by deliberately placing obstacles in the form of lattice defects in the path of dislocations. Name four lattice defects and the strengthening mechanisms caused by them. Order them according to the dimension of the lattice defects (zero to three-dimensional).

1.6 Spring elements in mechanical watch movements (setting lever springs, metallic hairsprings) are usually cold-rolled. Why?

1.7 Please name and explain three factors that decisively influence solid solution hardening.

1.8 Electrical sheets for transformers consist of BCC iron with 2-4% Si (solid solution, suppression of eddy currents). These sheets often have a Goss texture, i.e., the (100) directions of the crystals lie preferentially in the rolling direction and the {110} planes parallel to the sheet surface.

(a) Please draw a BCC unit cell.

(b) Draw an electrical sheet with Goss texture in the correct orientation into this unit cell and mark the rolling direction of type (100) in this plane of type {110}.

1.9 Drawn copper wires possess a (111) fiber texture, i.e., planes of type {111} are oriented perpendicular to the wire axis or the pulling direction of the wire.

(a) Draw an FCC unit cell.

(b) Draw a plane of type {111} as well as the direction of the wire axis or the pulling direction of the wire of type (111) perpendicular to it into the FCC unit cell.

2 Alloys

2.1 The aluminum casting alloy EN AC-AlSi10Mg (EN AC-43000) is used for both Sand Casting (S) and Permanent Mold/Die Casting (K). In the cast state, the properties differ. Why is the strength of the alloy higher after permanent mold casting than after sand casting?

2.2 The binary system Copper-Nickel is a phase diagram with complete solubility. What three conditions must generally be met for such a binary system to exist?

2.3 All Swiss coins from ten centimes to five francs have consisted of a CuNi25 alloy (Cu with 25% Ni) since 1968. Please describe, using the Copper-Nickel binary system, how the state of aggregation would change with increasing temperature for a five-franc coin if it were heated from room temperature to $1300°C$ with a gas burner.

2.4 What is the chemical composition of the first crystals of the CuNi25 alloy when this alloy is cooled from the melt?

2.5 Describe the state of this CuNi25 alloy at $1160°C$. Which phases are present in what proportions (Lever rule)? How are these phases chemically composed?

2.6 What is the composition of the last melt when this alloy is cooled?

2.7 Please describe what segregations are and to what extent they can occur in this coin alloy?

2.8 What disadvantages would segregations have in this coin alloy?

2.9 Aluminum-Silicon phase diagram: At the eutectic point, there are classic casting alloys. Why is the alloy with 12.5% Silicon in the Al-Si binary system a good casting alloy? Please name two arguments.

2.10 Briefly describe the structure of the microstructure of the alloy with 12.5% Si (casting alloy) and the alloy with 35% Si (piston alloy) at room temperature.

3 Iron-Carbon Diagram

3.1 Please determine, using the lever rule for the hypoeutectoid alloy L_1 (Fig 3.4), which phases are present in what proportions with what respective chemical composition at $800°C$.

3.2 Which phases with what chemical composition are present at $800°C$ for the eutectoid alloy L_2?

3.3 Please determine, using the lever rule for the hypereutectoid alloy L_3, which phases are present in what proportions with what respective chemical composition at $800°C$.

3.4 Please name two applications for hypoeutectoid steels.

3.5 Please name one application for hypereutectoid steel.

4 Materials Testing

4.1 Please briefly explain the meaning of the isotropic elastic material parameters: Young's Modulus E, Poisson's ratio ν, and Shear modulus G.

4.2 Please briefly explain the meaning of the plastic material parameters: 0.2% Proof Stress $R_{p0.2}$, Tensile Strength R_m, and Elongation at Break A.

4.3 Which parameter is usually of greater importance for a design engineer: the 0.2% proof stress $R_{p0.2}$ or the tensile strength R_m? Please justify your answer.

4.4 Using the stress-strain diagrams for EN AW-6082-T6 (Abb. 4.40 and 4.41), read the parameters Young's Modulus E, 0.2% proof stress $R_{p0.2}$, Tensile Strength R_m, and Elongation at Break A as accurately as possible.

4.5 Which steel is a spring steel with high 0.2% proof stress $R_{p0.2}$: a steel with 0.2% C or a steel with 0.7% C and 4% Si? Please justify your answer.

4.6 May an aluminum profile loaded in tension with an initial cross-section $A_0 = 500\ mm^2$ be loaded with 150 kN without plastically deforming if its 0.2% proof stress is 280 MPa?

4.7 Which value from the tensile test is decisive for a predetermined breaking point? Justify the choice.

4.8 When launching an F/A 18F Superhornet, a release rod (20 mm diameter) holds the aircraft. Engine thrust: $2 \times 98,000$ N. Catapult force: 1,235,000 N. The thrust must not plastically deform the rod, but the catapult must tear it (force $> 3\times$ force at tensile strength). Decide if a steel with $R_{p0.2} = 985$ MPa and $R_m = 1075$ MPa meets the requirements.

4.9 Excessive magnetic reversal losses occur in an electrical sheet. Which measurement methods would principally be suitable for determining grain size, texture, and chemical composition?

4.10 A stainless chromium-nickel steel has discolored. You need to distinguish between a thin temper color (max 10 nm oxide) and organic contamination. If it is oxide, you need the Cr/Fe ratio. EDX penetrates too deep. Which method do you choose?

5 Corrosion

5.1 Please explain the terms Anode, Cathode, and Electrolyte.

5.2 Please name four necessary conditions for a corrosion reaction to occur.

5.3 (a) Under what conditions is the nobler half-cell in a corrosion reaction the oxygen electrode?

(b) Under what conditions is the nobler half-cell in a corrosion reaction the hydrogen electrode?

5.4 Why does hydrogen corrosion generally proceed faster at acidic pH values than oxygen corrosion at neutral pH values?

5.5 Can the noble metal copper corrode in a humid environment at a neutral pH value?

5.6 Zinc layers are used as active corrosion protection on steel (e.g., power pylons). Explain why zinc corrodes instead of iron. Write the anodic and cathodic partial reactions. Which cathodic reaction would occur in an acidic electrolyte?

5.7 Case Study: A welded sheet of austenitic stainless steel 1.4301 corrodes along the weld seam. Discuss the cause and suggest two possible solutions.

5.8 Case Study: Gold-plated brass plugs are corroding under scratches in the gold layer.

(a) Does the gold act as active or passive protection?

(b) Why does the brass corrode strongly under small scratches?

(c) Suggest two measures to avoid this.

5.9 Pitting corrosion occurs in a 1.4301 stainless steel cooking chamber due to chloride concentration (130 mg/l). Suggest solutions.

5.10 You need a stainless steel for a water-carrying device (15-year life). A supplier offers a cheap high-sulfur (0.1% S) version and a dearer low-sulfur (0.01% S) version. Which do you choose and why?

6 Tribology and Surface Technology

6.1 Which is greater – static friction or kinetic friction?

6.2 Can the coefficient of friction take values greater than one? Name an example.

6.3 Name two advantages and two disadvantages of dry lubrication (graphite/MoS_2) vs. wet lubrication (oil).

6.4 Which metallic materials are susceptible to adhesive wear? Where is this exploited?

6.5 Name and explain three ways to improve coating adhesion.

6.6 Name and explain two advantages of electroless nickel deposition over galvanic.

6.7 Why are hexavalent chromium electrolytes banned (RoHS)? Name an alternative for galvanized screws.

6.8 Why does the oxide layer grow into the surface during aluminum anodizing? Name an alternative to chromic acid anodizing.

6.9 Name and explain two advantages of powder coatings over wet paint.

6.10 What are PVD and CVD coatings used for? Name three applications.

7 Steel Technology

7.1 What happens to steel in the ESR (Electro-Slag Remelting) process? What are the pros/cons and applications?

7.2 Why is martensite not in the iron-carbon diagram? What is the advantage of bainite over martensite?

7.3 Which microstructural constituents form if 34CrMo4 is cooled according to curve No. 4 in the TTT diagram (Fig 7.24)?

7.4 Is pearlite a phase?

7.5 Explain quench and tempering of carbon steels. Difference to austempering?

7.6 What is the heat treatment for strong and tough fine-grained structural steels?

7.7 Difference between carbonitriding and nitrocarburizing?

7.8 How is hardening depth defined for surface hardening vs. case hardening? Difference between surface-hardening steels and case-hardening steels?

7.9 Which elements increase hardenability (max surface hardness)?

7.10 Which elements increase the depth of hardening?

8 Steel Designation

8.1 Compare C35E and 34CrMo4. Name one advantage of each. Give their chemical compositions.

8.2 Derive the short name for material 1.4301 (0.05% C, 18% Cr, 10% Ni).

8.3 Which is intended for heat treatment: Quality steel or High-grade steel (Edelstahl)?

8.4 Which material numbers apply to unalloyed tool steels, alloyed tool steels, and high-speed steels?

8.5 Difference between C45 and C45E?

9 Special Steels

9.1 Why are high-alloy austenitic steels chosen for very low temps ($-50°C$)?

9.2 How can the high-temperature strength of steels be increased?

9.3 Advantage and disadvantage of maraging steels vs. heat-treatable steels?

9.4 Which is a good spring steel: 0.2% C or 0.56% C + 1.75% Si? Why?

9.5 Name three steel grades for automotive body stiffening (B-pillar, etc.).

9.6 1.4016 (0.7% C) is hard to weld. Suggest an alternative ferritic stainless steel for a washing machine drum. Which element helps weldability/corrosion?

9.7 Pitting in a 1.4301 tank due to chloride (70 mg/l). Name two prevention methods.

9.8 Advantage of seawater-resistant duplex steels vs. super-austenitic steels?

9.9 Pros/cons of cold-work vs. hot-work tool steels? Two applications for each?

9.10 Pros of HSS tools vs. ceramic tools? Main elements in HSS?

10 Cast Iron

10.1 Which use stable vs. metastable diagrams? Match: GJL, GS, GJN, GJS, GJV.

10.2 Why is austenitic cast steel GX5CrNi19-10 better for cryo tech than ferritic GE300?

10.3 Compare Nodular Cast Iron (GJS) vs. Grey Cast Iron (GJL). One advantage and application for each.

10.4 Match applications (Crankshaft, Pump housing, Grinding balls) to types (White cast iron, ADI, Austenitic cast iron).

10.5 How is the melt treated to create nodular graphite instead of flake graphite?

11 Aluminum

11.1 Why is aluminum a ”young” industrial metal (only approx. 100 years)?

11.2 Name five properties and resulting applications of aluminum.

11.3 Why replace Steel or Copper with Aluminum despite lower strength/conductivity?

11.4 List main elements and strengthening mechanisms for EN-AW 2XXX, 3XXX, 5XXX, 6XXX, 7XXX.

11.5 What causes the highest strength increase? (Solid solution, Work hardening, Natural aging, Artificial aging).

11.6 Which precipitate type gives greatest strength? (Coherent, Semi-coherent, Incoherent).

11.7 Compare 2024, 7075, 6061 regarding: Fatigue (T3/T4), Strength (T6), Corrosion, Weldability.

11.8 Which binary system are most casting alloys based on? Elements for precipitation hardening?

11.9 Name four forming processes and four casting processes for aluminum.

11.10 How is EN AW-2024 made corrosion resistant?

12 Non-Ferrous Metals

12.1 Which light alloys offer strength of heat-treatable steel but lower weight?

12.2 Why is Titanium corrosion resistant (biocompatible) despite being non-noble?

12.3 Name two negative properties of Magnesium preventing it from replacing Aluminum.

12.4 Which properties allow Ni-superalloys in turbine blades? How to increase creep strength?

12.5 Which Ni alloy is best for maritime atmospheres?

12.6 Which Ni alloy is used for soft magnetic cores in quartz watches?

12.7 How is high purity Copper produced?

12.8 Two applications of Zinc?

12.9 Advantage of Niobium/Tantalum over Tungsten/Molybdenum at room temp?

12.10 Why can gold wires be friction welded (piezo actuators)?

13 Ceramics and Glass

13.1 Three pros and three cons of ceramics vs. metals.

13.2 What is the Weibull modulus? Which has higher modulus: HIP or sintered Al_2O_3? Effect of sample volume on Weibull plot?

13.3 Silicate vs. High-performance ceramic? Why is single-crystal Al_2O_3 transparent but poly- not?

13.4 Three requirements for refractory ceramics.

13.5 Components of porcelain? Function of glaze? Advantage of Cordierite?

13.6 Properties of Yttrium-stabilized Zirconia (Mechanical & Electrical).

13.7 Decisive advantage of glass-ceramic?

13.8 Why is float glass perfectly flat?

13.9 Components of window glass? Use for oven window? Alternative? Why is chemically toughened glass stronger?

13.10 Structural feature of piezoelectric ceramics?

14 Polymers

14.1 Match: Thermoplast, Thermoset, Elastomer to Cross-link density (Many, Few, None). Give examples.

14.2 Structural features increasing strength/melting point of thermoplasts? Which melt $> 200°C$?

14.3 Write a biaxial stress tensor for a pressurized container. How to increase strength in stress direction without fibers?

14.4 Higher strength: PE or PS? Why? Copolymer for Styrene to improve toughness?

14.5 Advantage of POM vs PA?

14.6 Advantage of EPDM vs Classic Elastomers?

14.7 Applications of thermosets?

14.8 Sources of microplastic?

14.9 Problem with oxo-degradable plastics?

14.10 Name a biodegradable plastic and application. Why not suitable for all uses?