Level of Expectations – Aerospace Material Science and Processes 1+2

Topic	**Comprises, amongst others, the following tasks and problem statements:**
Fundamentals of materials science and processes	• Definition of the terms materials, process. • Classification of materials: metals, polymers, composites, ceramics. • Material properties: physical, mechanical, chemical and processing properties. Characteristics of the material groups.
Structure of materials	• Atomic structure • Periodic table • Electrons in atoms: Bohr and wave-mechanical atom models, quantum number, electron configuration, electronegativity, primary and secondary bond • Atomic bonding: ionic, covalent, metallic and Van der Waals bonds, sphere-spring model

Material characterization and mechanical properties	• Mechanical properties: strength, stiffness, toughness, ductility, hardness, durability, fatigue, tribology and friction value.
	• Test methods: characteristics of destructive and non-destructive testing.
	  ○ Tensile test: strain-stress curve
	  ○ Hardness: Brinell, Vickers, Rockwell methods
	  ○ Creep and fatigue testing: strain-time, Wöhler curve
	  ○ Impact bending test

Metals and ceramics	• Crystalline and amorphous materials • Common lattice structures: body centered cubic, face centered cubic, hexagonal closed packed. • Lattice defects: point defects, linear defects, interfacial defects, bulk defects. • Deformation mechanisms: elastic and plastic deformation • Strengthening mechanisms: solid solution, grain size reduction, strain hardening • Development of crystal structures: single and polycrystalline crystals, diffusion, phase diagrams. • Iron steel: phase amounts in phase diagram, influence of heat treatments (hardening and annealing), main groups of iron steel (carbon steel, stainless steel) • Non-ferrous metals: aluminum, copper, magnesium, titanium, nickel and their main characteristics • Ceramics: consumer, functional, and structural, manufacturing processes (forming, sintering), mechanical characteristics
Plastics	• Structure and fundamental properties of thermoplastics, elastomers, thermosets • Copolymerization: alternating, statistical, block, graft • Mechanical, thermal and electrical properties in comparison to metals and ceramics • Polymer synthesis: polymerization, polycondensation, polyaddition
Composites	• Classification (according to their reinforcement and matrix), materials and properties • Manufacturing of composites: winding, braiding, weaving, draping, AFP, pultrusion, RTM

Introduction to additional properties	• Thermal: heat capacity, thermal expansion, heat conduction, thermal stresses, thermal properties of different materials (metals, ceramics, polymers) • Electrical: Ohm's law, electrical conductivity and resistivity, semiconductors (intrinsic and extrinsic) • Degradation of polymers: mechanisms (thermal oxidation, ultraviolet radiation, chain scission, hydrolysis) • Corrosion: types of corrosion, corrosion protection, corrosion rates • Optical: basics (electromagnetic radiation, electromagnetic spectrum, light interaction with solids, atomic and electronic interactions), refraction, optical properties of metals and nonmetals • Magnetic: basics (magnetic dipoles, magnetic parameters), magnetic field vectors, magnetic parameters, types of magnetism

Material selection	• Connections between part design process and material selection by the major design stages (concept design, embodiment design, detail design)
	• Material selection methodology: the four steps in material selection (translation, screening, ranking, documentation/research), revolutionary and evolutionary materials,
	• Material indices
	  ○ Performance, functional requirements, geometrical constraints and material
	  ○ Structural and material efficiency coefficients
	• Material property charts (Ashby Plots)

Introduction to material processes	• Definition of the term process
	• Classification of material processes with attributes in terms of cohesion: primary shaping (casting injection molding), forming (forging, deep drawing, stretch forming, creasing, shear forming), separating, joining, coating and modification of substance properties
	• Primary shaping
	  ○ Classification according to nature of shapeless material
	  ○ Casting
	  ▪ Material characteristics (casted iron, casted steel, casted aluminum, high-performance materials)
	  ▪ Processes: lost form (sand casting, investment casting, lost foam casting), permanent form (mold casting, die casting)
	  ▪ Construction guidelines: volume shrinkage, casting defects
	  ○ Primary shaping from plastics: extrusion, injection molding, reinforced polymers
	  ○ Primary shaping by additive manufacturing: selective laser melting, electronic beam melting
	• Forming
	  ○ Classification according to DIN 8582 and to ASME
	  ○ Bulk forming: forging processes, extrusion, rolling processes
	  ○ Sheet forming: bending of sheet metals, bending of metal, deep drawing, stretch forming, spinning, shot peen forming
	  ○ Forming processes of plastics and composites: vacuum forming process, diaphragm forming process, thermoforming of composites, blow molding process

- Joining
  - Introduction: form closure, force closure, material closure
  - Characteristics of joining by assembling, by processing amorphous materials, by mechanical means, by forming processing, by welding, by soldering/brazing, by means of adhesives
  - Joining of textiles and ceramics
- Separating
  - Cutting
    - Definitions according to DIN 8588
    - Shearing: open and closed cut, fine blanking, limitations and problems
    - Wedge cutting
    - Water jet cutting
    - Thermal separation processes: oxy-fuel cutting, plasma cutting, laser cutting, laser fusion cutting, sublimation cutting
  - Machining
    - Introduction: machining technology, chip formation, cutting forces, cutting materials, tool geometry
    - Machining with geometrically defined cutting tool: turning, drilling, milling, broaching, sawing
    - Machining with geometrically undefined cutting tool: grinding, honing, lapping
- Cleaning
  - Definition and purpose
  - Classification (DIN 8592): blast, mechanical, flow, solvent, chemical and thermal
  - Selection according to component properties, pollution status, cleanliness requirements, plant data
  - Analysis methods: visual inspection, fluorescence, thermography
- Coating
  - Definition and purpose
  - Classification: liquid, plastic, mushy, solid, gas/vapor, ionized, welding, soldering
  - Processes
- Property modification
  - Classification (DIN 8580): strengthening by forming, heat treatment, thermomechanical treatment, sintering firing, magnetization, irradiation, photochemical processes
- Composite processing
  - Processes overview for preform, prepreg and wet composite processes
  - Materials: non-crimp fabrics, textiles
  - Tape laying processes: AFP, ATL
  - Hand layup
  - Braiding

Evaluation	• Life Cycle Assessment (LCA)
	  ○ Definition and phases of a LCA: goal and scope definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and interpretation
	• Technology Readiness Level (TRL) and costing
	  ○ TRL definitions, purposes, assessments
	  ○ S-Curve Model with emergence, rapid improvement, declining improvement, maturity
	  ○ Financials in development: active and passive accounting
	  ○ Basics of costs: revenue, fixed costs, variable costs, total costs, breakeven
	  ○ Costs in engineering: economies of scale, economies of scope, modularization, mass-customization, function integration, rule of ten
	  ○ Definition of cost calculation terms: return of investment, contribution margin, capacity utilization rate, manufacturing cycle efficiency, defect rate, lead-time, recurring and non-recurring costs.
	  ○ Marginal costs, machine costs

Recycling	• Recycling of aerospace aluminum components: general process stages of scrap pre-treatment and scrap refining, techniques for separating aluminum scrap from non-aluminum components, method to sort aluminum scrap by sort of alloy (Laser Induced Breakdown Spectroscopy) • Recycling of CFRP: techniques (mechanical, pyrolysis, chemical) with their characteristics, advantages, and disadvantages

Selected references:

1. Bargel, H.-J., Schulze, G.: Werkstoffkunde. Springer Verlag, 2008.
2. Bautsch, H.-J., Bohm, J., Kleber, I.: Einführung in die Kristallographie. Verlag Oldenbourg, 2002.
3. BDS-Fachbuchreihe Bd. 14: Fragen und Antworten aus der Werkstoffkunde. Vertriebsgesellschaft des BDS, 1975.
4. Berns, H., Theisen, W.: Eisenwerkstoffe – Stahl und Gusseisen. Springer Verlag, 2008.
5. Bergmann, W.: Werkstofftechnik Teil 1+2. Carl Hanser Verlag, 2008.
6. Dietrich, H.: Mechanische Werkstoffprrüfung. expert Verlag, 1994.
7. Haasen, P.: Physikalische Metallkunde. Springer Verlag, 1994.
8. Hellerich, W., Harsch, G., Haenle, S.: Werkstoffführer – Kunststoffe. Hanser Fachbuchverlag, 2004.
9. Hornbogen, E., Eggeler, G., Werner, E.: Werkstoffe, Aufbau und Eigenschaften. Springer Verlag, 2009.
10. Ilschner, B., Singer, R. F.: Werkstoffwissenschaften und Fertigungstechnik, Eigenschaften, Vorgänge, Technologien. Springer Verlag, 2005.
11. Kalpakjian, S., Schmid, S.R., Werner, E.:Werkstofftechnik. Pearson, 2011.
12. Menges, G.: Werkstoffkunde Kunststoffe. Hanser Fachbuchverlag, 2002.
13. Merkel, M., Tomas, K.-J.: Taschenbuch der Werkstoffe. Carl Hanser Verlag, 2008.
14. Schatt, W., Worch, H., Werkstoffwissenschaften. Wiley-VCH Verlag, 2002.
15. Schmidt, W., Dietrich, H.: Praxis der mechanischen Werkstoffprüfung. expert Verlag, 1999.
16. Shackelford, J. F.: Werkstofftechnologie für Ingenieure. Pearson Studium, 2007.
17. Weißbach, W., Dahms, M.: Aufgabensammlung Werkstoffkunde und Werkstoffprüfung. Fragen – Antworten. Verlag Vieweg + Teubner, 2008.
18. Werner, E., Hornbogen, E., Jost, N., Eggeler, G.: Fragen und Antworten zu Werkstoffe. Springer Verlag, 2010.