Master examination

“Metallic Materials (Ferrous Materials)”

31.08.2015

Name:

Matriculation number:  
Signature:

<table>
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<th>Task</th>
<th>Maximum points</th>
<th>Points achieved:</th>
<th>Points after review (only additional points)</th>
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You need 44 % to pass this examination.

The examination is divided into two parts. The final result is calculated as follows:

50 % Written examination (“Ferrous Materials”)

50 % Written examination (“Microstructures, Microscopy & Modelling”)
Task 1  General  4 Point(s)

As can be seen from Fig.1, the element iron is known as the symbol Fe with the atomic number of 26 and its atomic mass is 55.8. Since it has low chemical stability, it is rarely found as a pure substance but rather as an oxide, sulphide, carbonate, or silicate. With the advent of the Iron Age (~BC 1500), Fe has been introduced to a number of application and it is universally used until now.

Why do you think Fe is universally, technically applicable? List four reasons based on the information provided in Figs.1-3 and explain. (4 points)

Appendix 1

Figure 1: Position of iron in the periodic table of the elements and its physical properties.

Figure 2: Relative abundance of elements in the Earth’s upper crust with respect to the atomic number, Z (Gordon B. Haxel, Sara Boore, and Susan Mayfield from USGS).

Figure 3. Different phases of pure Fe with respect to temperature
Task 2 Crystal structure 8 Point(s)

Consider a cubic crystal structure which consists of two kinds of atoms, A, and B, respectively. As shown in the Appendix 1, the type “A” atoms are located at the edges of the cubic unit cell, and the type “B” atoms are located at the face centre of the unit cell. Note that the atoms are closed packed in the unit cell as in Appendix 1 b.

The radius of “A”-Atoms is: $R_A$

The radius of “B”-Atoms is: $R_B = R_A / 1.4$

Appendix 1

(a) Projected view  (b) View on (100) plane

a) Calculate the packing density of this unit cell. (6 Points)
b) What is the packing density of an fcc unit cell which is consist of one type of atoms? (1 Point)

c) What is the reason for the difference between packing densities in a) and b)? (1 Point)
Task 3  
**Elastic properties**  
3 Point(s)

Sketch the temperature dependency of the Young’s moduli of a ferritic and an austenitic steel in **Appendix 1**. Fill in the unit of the Young’s modulus in the y-axis for the unit of the Young’s Modulus. Mark the approximate values at room temperature. (3 Points)
Task 4  Alloying elements  15 Point(s)

In the metastable Fe-Fe₃C phase diagram, examples of three basic phase transformation reactions can be found.

Write down the respective transformation reactions (reacting phase(s) → produced phase(s)) and the carbon contents of all participating phases. (12 points)

1: Peritectic reaction:

Equation (phases): ___________________ → ___________________

C contents: ______________________________________

2: Eutectic reaction:

Equation: ___________________ → ___________________

C-contents: ______________________________________

3: Eutectoid reaction:

Equation: ___________________ → ___________________

C-contents: ______________________________________

What are the temperatures for respective reaction? (3 Points)

Peritectic reaction: T=_________________

Eutectic reaction: T=_________________

Eutectoid reaction: T=_________________
Task 5  

**Austenitic phase transformation**  

9 Point(s)

a) Complete the given diagram in **Appendix 1**. Add the microstructures which form at elevated temperatures and describe the transformation mechanism briefly.  

*(6 Points)*

**Appendix 1**

![Diagram of austenitic phase transformation](image)

b) Name the microstructures that exist in a steel grades with 0.002, 0.4 and 0.8 mass-% carbon respectively after air cooling *(3 Points)*.
The phase transformation from austenite to ferrite-pearlite is among other things diffusion controlled.

a) Name the 2 kind of diffusion which can take place in the solid state. Which of these 2 kinds is faster and controls the diffusion? (2 Points)

b) Explain how it is possible to achieve a 100% pearlitic microstructure for a hypoeutectoid steel? (1 Point)

c) Give the empirical equation to calculate the lamellar distance in pearlite colonies. (1 Point)

d) Explain the impact of a smaller lamellar distance on:
   - the toughness
   - the strength
of pearlitic steels. (1 Point)
Task 7:  

The formation as well as the morphology of martensite is dependent on the C-content of the steel.

a) Sketch the $M_s$-temperature in the diagram located in the middle of Appendix 1. (1 Point)

b) Sketch the volume fractions of i) retained austenite, ii) lath martensite and iii) plate martensite in the lower diagram of Appendix 1. (3 Points)
c) A steel with 0.9 mass-% C should be heat treated to achieve a complete martensitic microstructure. What should be considered for the heat treatment (temperature) and the cooling medium to achieve a complete martensitic microstructure? (4.0 Points)
Task 8  

bainite phase transformation  

8 Point(s)

A steel has been austenized, quenched to different temperatures below $A_{c1}$ and afterwards isothermal treated at this temperatures.

a) Sketch the areas where pearlite and bainite formation takes place in Appendix 1. (2 Points)

Appendix 1

![Diagram showing temperature x log t with areas A, B, C, and D marked at different temperatures](image)
b) In **Appendix 2** you can find the carbide distribution after the different heat treatments A, B, C and D. Complete the given table in **Appendix 2** by combining the corresponding heat treatment of **Appendix 1** with the given microstructures. Add the approximate length of the carbides in the given table. (4 Points)

**Appendix 2**

<table>
<thead>
<tr>
<th>Microstructure</th>
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<td>![Microstructure 1]</td>
<td>![Microstructure 2]</td>
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<tr>
<td>![Microstructure 3]</td>
<td>![Microstructure 4]</td>
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<table>
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<tr>
<th>Heat treatment</th>
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</table>

<table>
<thead>
<tr>
<th>Length of carbides</th>
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<tbody>
<tr>
<td></td>
<td></td>
</tr>
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<td></td>
<td></td>
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</tbody>
</table>

(α – white, carbides – black)

c) Based on the microstructures and time-temperature profiles from task a) and b) the formation of pearlite and bainite can be classified more detailed. Name the microstructures based on the information you have derived in the previous tasks. (2 Points)
Task 9  aging  5 Point(s)

A low alloyed steel with 0,01 mass% C has been solution annealed at 720 °C and subsequently quenched.

a) Tensile testing has been carried out immediately after quenching. One specimen has been tempered at 60°C for 10 minutes. Correlate the two different treatments with the stress-strain curves given in Appendix 1. (1 Point)

Appendix 1

b) The difference between the stress-strain curves is based on aging-effects. What are the conditions that aging can take place in steels? (2 Points)
c) Which alloying elements are mandatory for aging in steels? Where are these elements located in the lattice (1 Point)

d) Which process uses aging to achieve better mechanical properties? (1 Point)
Task 10  

CCT Diagram  

10 Point(s)

A CCT diagram for a 34Cr4-steel is given in Appendix 1.

a) Sketch the COMPLETE heat treatment for a bainitic-martensitic microstructure with the lowest hardness based on the cooling paths given CCT diagram. The holding time and temperature for each heat treatment step should be provided. Cooling rate must be given in terms of $t_{8/5}$. Furthermore, determine the hardness and phase fraction of bainite and martensite in the final structure. (4 Points)

Appendix 1:

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Cu</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
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<tr>
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<td>0.23</td>
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<td>0.013</td>
<td>1.11</td>
<td>0.18</td>
<td>0.05</td>
<td>0.23</td>
<td>&lt;0.01</td>
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Austenitization temperature 850°C  
(holding time 8 min) heating in 3 min

A Area of austenite  
F Area of ferrite formation  
P Area of pearlite formation  
B Area of bainite formation  
M Area of martensite formation

Hardness in HRC/HV  
1;3;  
Volume fraction in %

Diagram showing CCT diagram with cooling paths and temperature-time relation.
b) When the cooling path passes over the pearlitic area (P), a sudden change in cooling rate occurs. What is the reason? (2 Points)

c) Explain the difference between a CCT diagram and a TTT diagram in terms of the heat treatment schedule. (4 Points)
Task 11  Technical heat treatment  10 Point(s)

a) What is the purpose of the recrystallization treatment? Which mechanical properties can be improved by such a treatment? (2 Points)

b) In industrial production lines, two different approaches are adopted for recrystallization annealing. Name these approaches and sketch the time-temperature cycle for both. Compare the temperature regime, cooling rates, and duration for the heat treatment. (8 Points)
Task 12  Quenching and tempering  6 Point(s)

According to the DIN EN 10052 standard quenching and tempering is combined heat treatment.

a) Sketch the quench and tempering process in Appendix 1. Add $A_c$, $B_s$ or $M_s$-temperature lines to indicate the general temperature regime and cooling rate during the process. (4 Points)

Appendix 1

b) Which mechanical properties are improved after the quench and tempering treatment in comparison with the steels after quenching? (2 Points)
Task 13 technical heat treatment II 3 Point(s)

a) What is the temperature range for normalising? List the temperature range depending on the C concentration; i) for hyper-eutectoid steels, and ii) for hypo-eutectoid steels? (2 Points)

b) What is the aim of normalizing heat treatments. (1 Point)
Task 14 Microstructures 6 Point(s)

Following micrographs show microstructures of Fe-C alloys with different C concentrations at room temperature. Assuming that they were cooled very slowly from the melt, write the corresponding C concentration and the observed phases shown in the micrographs based on Appendix 1. The carbon concentration of the alloys are 0.01, 0.2, 0.8, 1.2, 4.3, 5 mass%. (6 Points)

Appendix 1

(1)  (2)  (3)

(4)  (5)  (6)