Master examination

„Metallic Materials

Ferrous Materials“

22.07.2015

Name:

Matriculation number: **Signature:**

Task	Maximum points	Points	Points after review (only additional Points)
1	12.5		
2	5		
3	9.5		
4	8		
5	6		
6	13		
7	4		
8	8		
9	9		
10	12		
11	5		
12	8		
Sum	100		

You need 44 % to pass this examination.

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

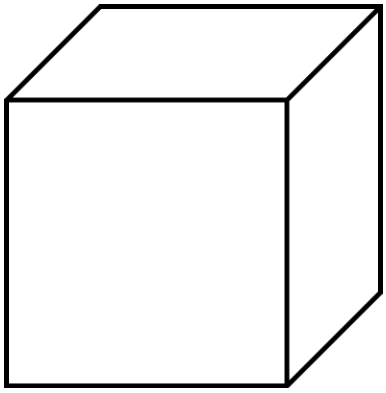
50 % Written examination (“Ferrous Materials”)

50 % Written examination (“Microstructures, Micoscopy & Modelling”)

Task 1 Crystal structure 12.5 Point(s)

Pure Fe exists in the form of *α*-Fe at room temperature.

a) Mark the all the positions of Fe atoms (●) and possible octahedral interstices (○) for interstitial atoms in a unit cell of *α*-Fe at room temperature given right. (3 Points)



b) Calculate the theoretical density of *α*-Fe by using the given values: atomic weight of Fe:55.847, Avogadro number:6.022×10^{23}, lattice parameter of *α*-Fe:2.86 Å. Compare it with the real value of 7.874 g cm^{-3}. What is the reason for the discrepancy? (3 Points)

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c) Imagine an octahedral interstitial site in α-Fe as placed in the centre of a distorted octahedron (Fig. 1) surrounded by six metal atoms at the corners. What are the two characteristic distances (d_1, d_2) between the metal atoms and the octahedral interstitial site? Assume that the side length of the octahedron is a. Hint: $a \neq b$. (2 Points)

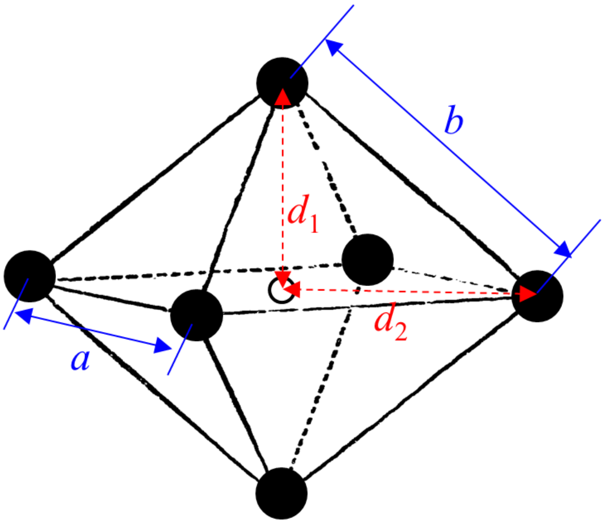

Fig. 1: An octahedral interstitial site in a bcc crystal.

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d) Characteristics of α-Fe at room temperature are given in **Table 1**. Complete the table for the missing values. (2.5 Points)

Table 1. Characteristic properties of pure α-Fe at room temperature.

	Values
Crystal structure	
Lattice parameter / Å	2.86
Number of atoms per unit cell	
Number of nearest neighbours	
Number of octahedral interstitial sites per unit cell	
Size of octahedral interstitial sites / Å	0.19
Number of tetrahedral interstitial sites per unit cell	
Size of tetrahedral interstitial sites / Å	0.36

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e) Both hydrogen and carbon can be interstitially incorporated in *α*-Fe. Their atomic radii are 0.32 and 0.77 Å, respectively. Compare these atomic radii with the size of interstitial sites given in Table 1. Name one phenomenon involved in the mechanical properties of steel caused by H. In addition, explain how C can be interstitially incorporated in *α*-Fe and what effects such incorporation can cause (2 Points).

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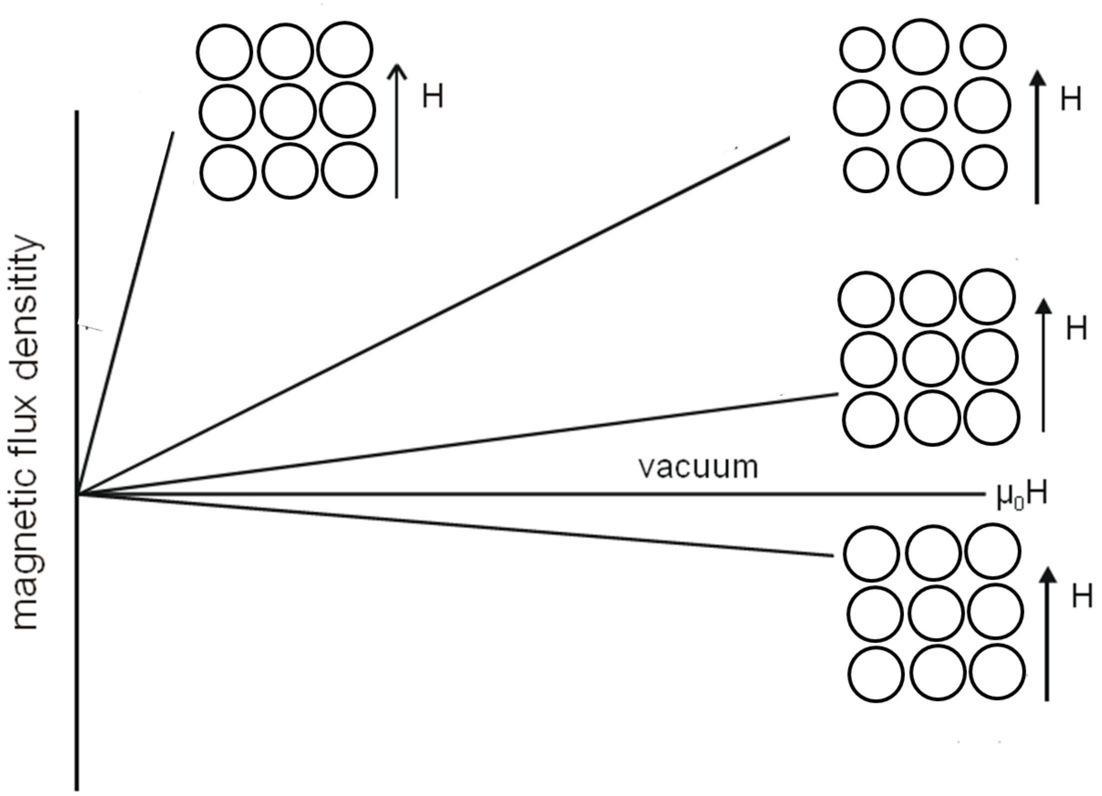
Task 2 Physical properties 5 Point(s)

a) Describe the different types of magnetism occurring in metals. Sketch the magnetic moments for these types of magnetism in **Figure 1.** (4.0 Points)

Figure 1



b) Give a short explanation for the Curie temperature $T_{c.}$ (1,0 Point)

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Task 3 Alloying elements 9.5 Point(s)

When Fe is alloyed with C higher than 0.05 wt%, graphite is supposed to form as an equilibrium phase at room temperature. However, this is rarely observed; instead, cementite forms as a metastable phase.

a) Draw the metastable phase diagram of the Fe-C system. Indicate the present phases (L: liquid, α, δ: ferrite, γ: austenite, θ: cementite) in each phase field. The plot must include carbon content range of 0-6 wt% and temperature range of 500-1600°C. (5.5 Points)

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b) Cementite can be classified into three types: (i) primary, (ii) secondary, and (iii) tertiary. What is the criterion of the classification? Mark the relevant boundary line and C concentration range (in wt%) for respective cementite type in the phase diagram that you have plotted in (a). (3 Points)

c) Indicate the area(s) where pro-eutectoid ferrite is formed. (1 Point)

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Task 4 Alloying elements II 8 Point(s)

Fig. 1. shows the solubility of (a) N and (b) H in iron with respect to temperature.

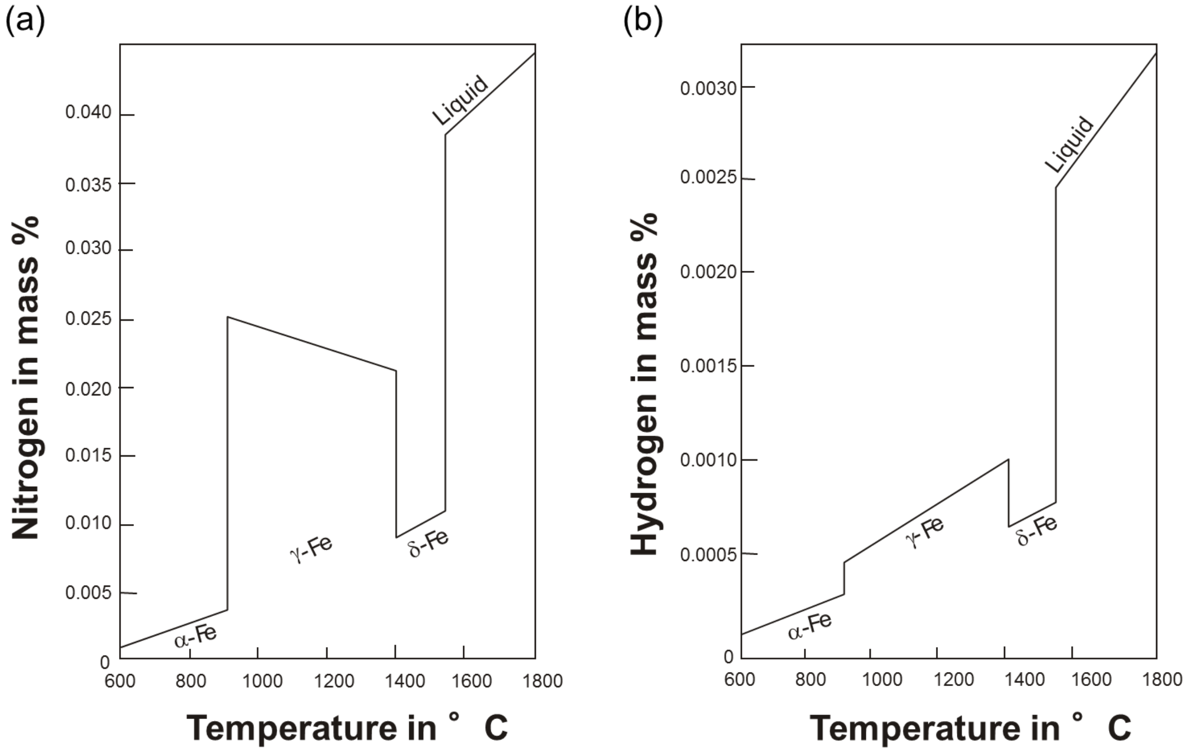

Fig. 1: Metastable phase diagram of the Fe-C system.

a) Why the solubility shows sudden jump at the phase transformation temperature (2 Points)?

b) It is observed in Fig. 1a that nitrogen solubility in Fe shows a negative temperature dependency while it shows a positive dependency for other phases. What is the reason? Explain based on the Sieverts' law and the given Gibbs free energy (Δ*G*) for the nitrogen dissolution in each phases (*T*: temperature). (4 Points)

$$\frac{1}{2}N_2 = [N]_{\alpha-Fe} \qquad \Delta G = 8347 + 9.9T \text{ cal mol}^{-1}$$

$$\frac{1}{2}N_2 = [N]_{\gamma-Fe} \qquad \Delta G = -1920 + 15.2T \text{ cal mol}^{-1}$$

$$\frac{1}{2}N_2 = [N]_{\delta-Fe} \qquad \Delta G = 6083 + 11.8T \text{ cal mol}^{-1}$$

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c) Based on your answer for (b) and Fig. 1b, can you guess whether the hydrogen dissolution in iron is endothermic or exothermic? (2 Points)

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Task 5 phase transformations 6 Point(s)

In metallic materials the solid-solid phase transformations can result in a change of the crystal structure.

a) What is the name of a solid-solid phase transformation which results in a change crystal structure? (1 Point)

b) Name all allotropic modifications of iron and the temperature ranges where they are stable. (3 Points)

c) Name two metals beside iron, which have solid-solid phase transformations with changes of the crystal structure. (2 Points)

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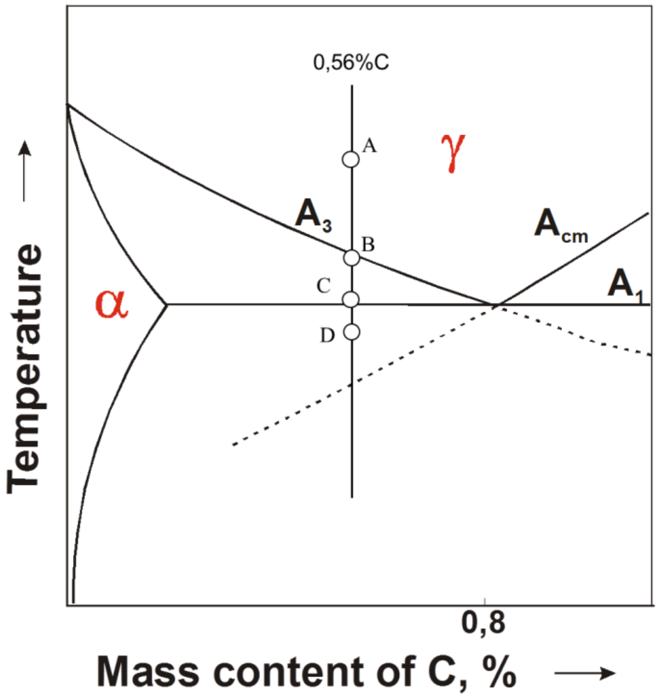
Task 6 ferrite-pearlite phase transformations 13 Point(s)

The formation of ferrite – pearlite microstructures can be explained using the Fe-Fe_3C-diagram given in **Appendix 1**.

Appendix 1



a) Calculate the Ferrite-Austenite ratio in Point C for a steel with 0.56 Mass-% Carbon. (5 Points)

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b) Sketch the microstructures at Point A, B, C and D, respectively. Consider that the specimens have been cooled down under equilibrium-conditions to the corresponding temperature. Indicate all phases (8 Points).

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Task 7 martensitic-phase transformation 4 Point(s)

Martensite has a higher strength compared to austenite. Name 4 effects which contribute to the high strength of martensite. (4 Points)

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-
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Task 8 bainitic phase transformations 8 Point(s)

Bainitic steels combine a good combination of strength and toughness. The bainitic phase transformation is a mixture of diffusion controlled and displacive transformation.

a) Explain the bainitic phase transformation for “lower bainite” and “upper bainite” for steel (carbon content approx. 0.5 Mass-%). Draw a sketch to illustrate the phase transformation for both cases. In which temperature ranges does the phase transformation take place? (6 Points)

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b) Besides the bainitic ferrite, secondary phases might be present in bainite. Name at least two of them. (2 Points)

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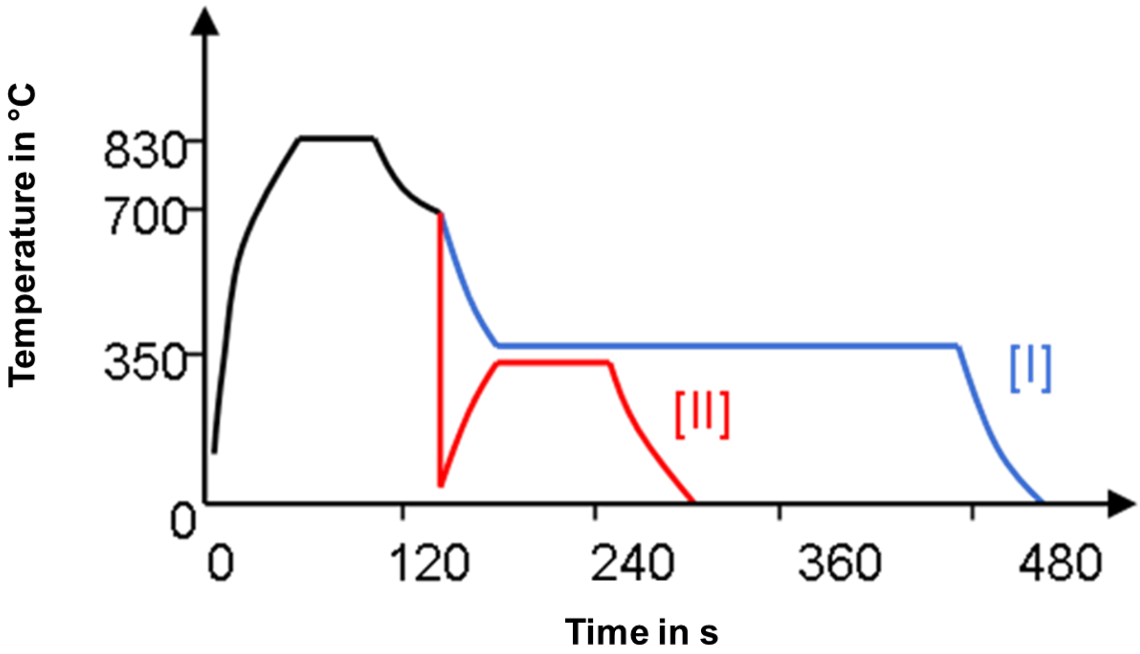
Task 9 Aging I 9 Point(s)

There are two industrial heat treatments to avoid aging of steel (see **Figure 1**).

Figure 1



a) Complete table 1 using “↓” to indicate a small impact and “↑” to indicate a big influence. (4 Points)

	Annealing cycle I	Annealing cycle II
Under cooling		
saturation		
Nuclei density		
Distance between precipitations		

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b) Describe and sketch the carbide distribution in the microstructure after each annealing treatment. (4 Points)

c) What is the disadvantage of annealing cycle II for industrial application? (1 Point)

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Task 10 TTT-diagrams 12 Point(s)

Heat treatments can be used to control the microstructure and therefore the mechanical properties of steels. In **Appendix 1** there is a TTT-diagram for the bearing steel 100Cr6. The following microstructures should be achieved:

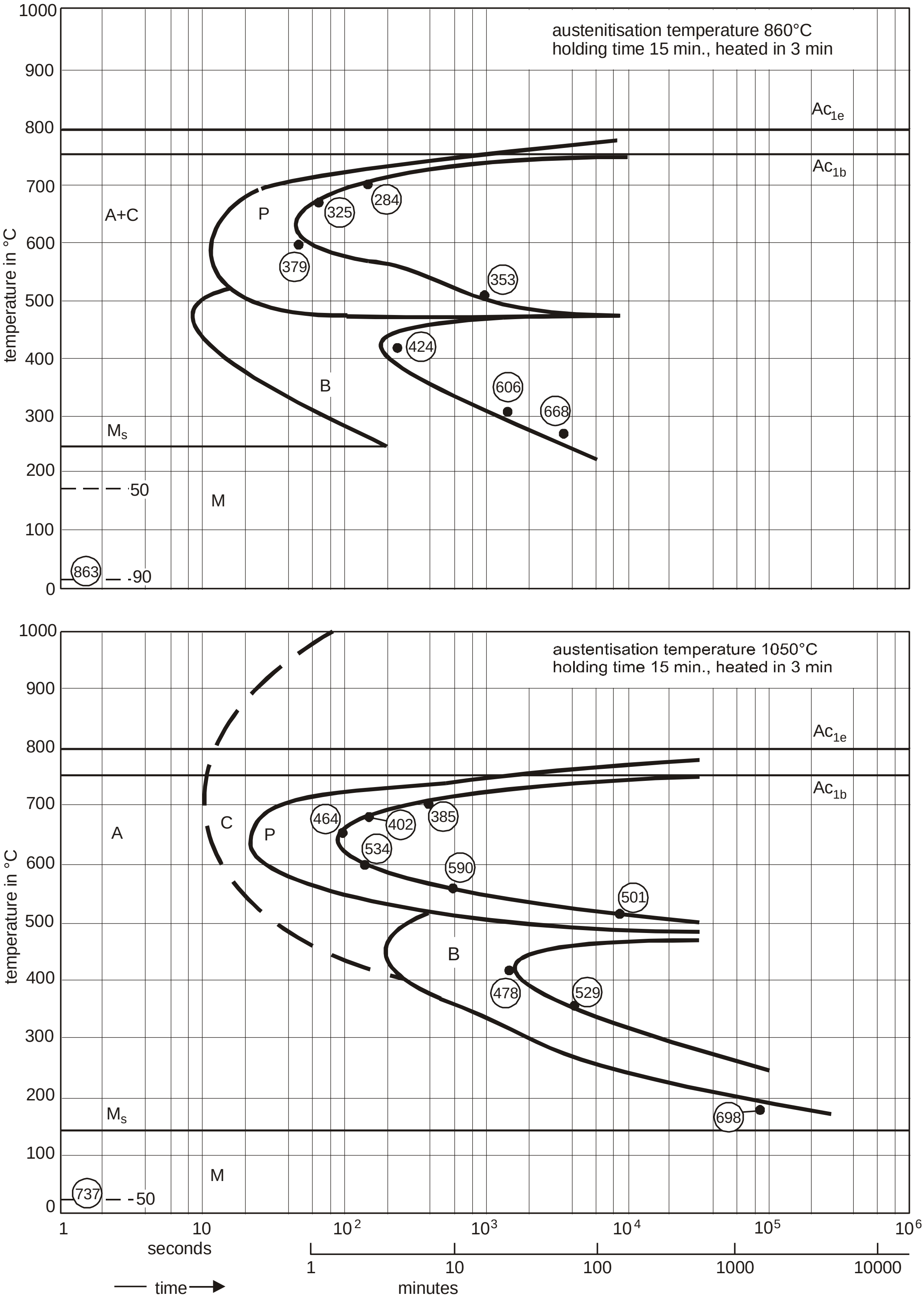
- 100 % pearlite and carbides with maximum hardness
- 100 % bainite and carbides with lowest hardness.

a) Based on the TTT diagram given in **Appendix 1**, suggest heat treatment schedules of 100Cr6 for obtaining the two desired microstructures above by sketching the complete temperature – time diagrams starting and ending at room temperature. Assume a small sample size. Start from the room temperature and show the temperature and time period for each step (8 Points).

b) Give an explanation, why the region of metastable austenite is marked with "A+C". Furthermore, explain the terms „inhomogeneous“ and „homogeneous“ austenite (4 Points).

Appendix 1: Time-Temperature-Transformation diagram (TTT) of 100Cr6

Chemical composition, mass contents in %	C	Si	Mn	P	S	Cr	Cu	Mo	Ni	V
	1,04	0,26	0,33	0,023	0,006	1,53	0,20	<0,01	0,31	<0,01



A	region of austenite	P	region of pearlite transformation
A+C	region of austenite and carbide	B	region of bainite transformation
C	region of carbide transformation	50,90...	microstructure constituents in %
◯	hardness in HV		

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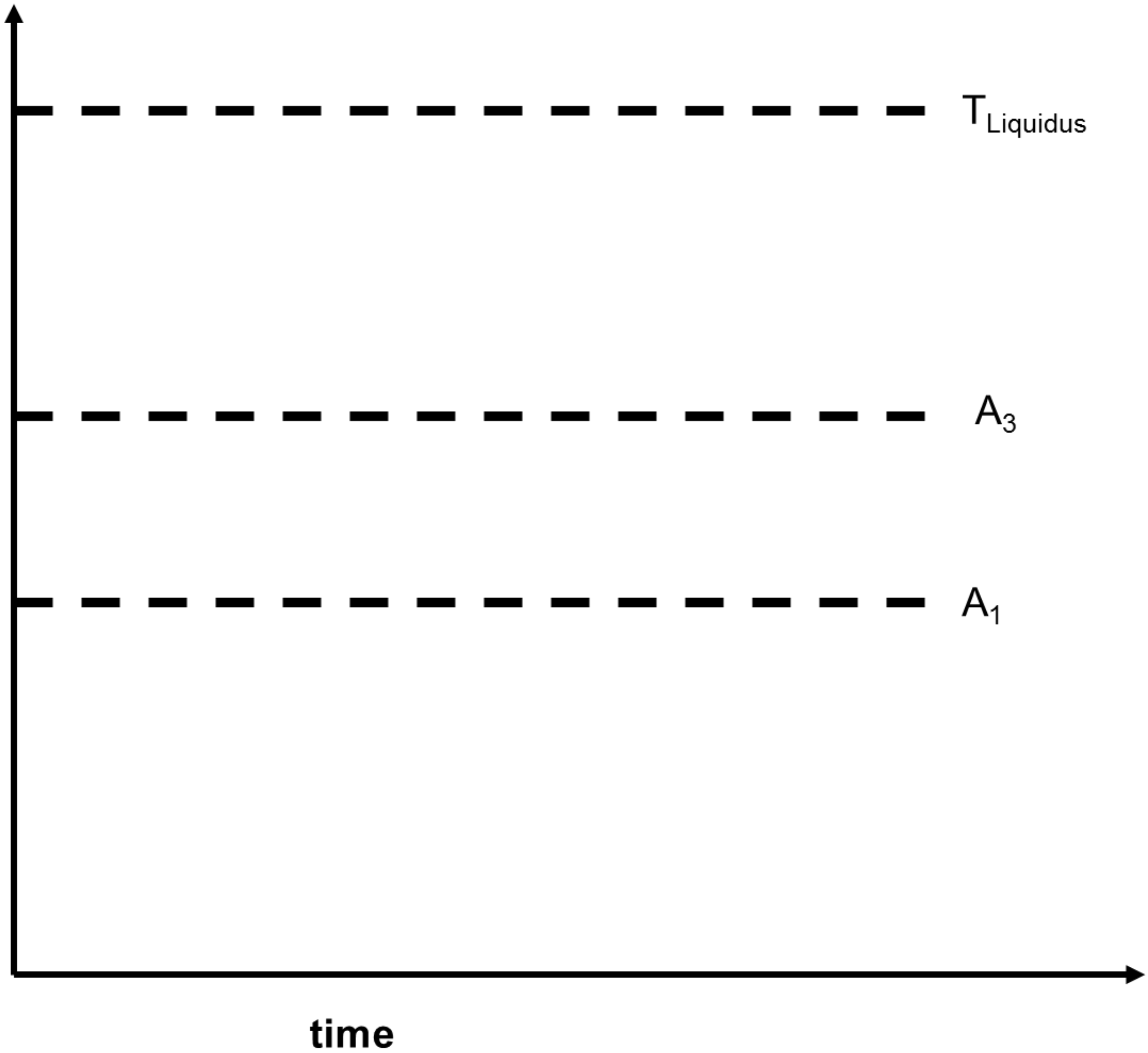
Task 11 Technical heat treatments 5 Point(s)

a) It is likely that macroscopic segregation may appear during casting process. Can you suggest one technical heat treatment employed to reduce such local differences in the chemical composition due to the segregations? Sketch the heat treatment steps below with appropriate annealing temperature and time (4 Points)?



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b) By eliminating the local difference in composition, this kind of heat treatment would produce the components with better quality. However, it is rarely employed for everyday products. Explain why (1 Point).

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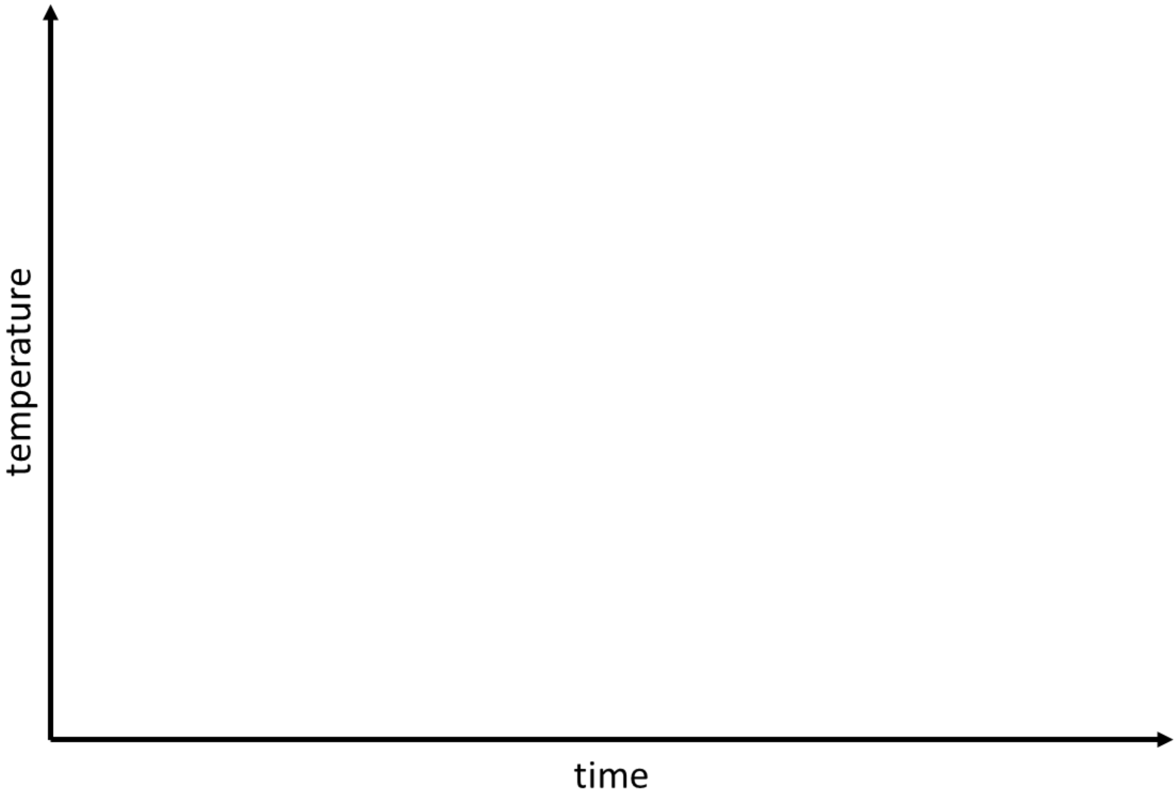
Task 12 Technical heat treatment 8 Point(s)

a) Sketch the time-temperature cycle for the “Quench and Tempering” process in **Figure 1**. Indicate all phase transformations which occur in different steps during the heat treatment (4 Points).

Figure 1



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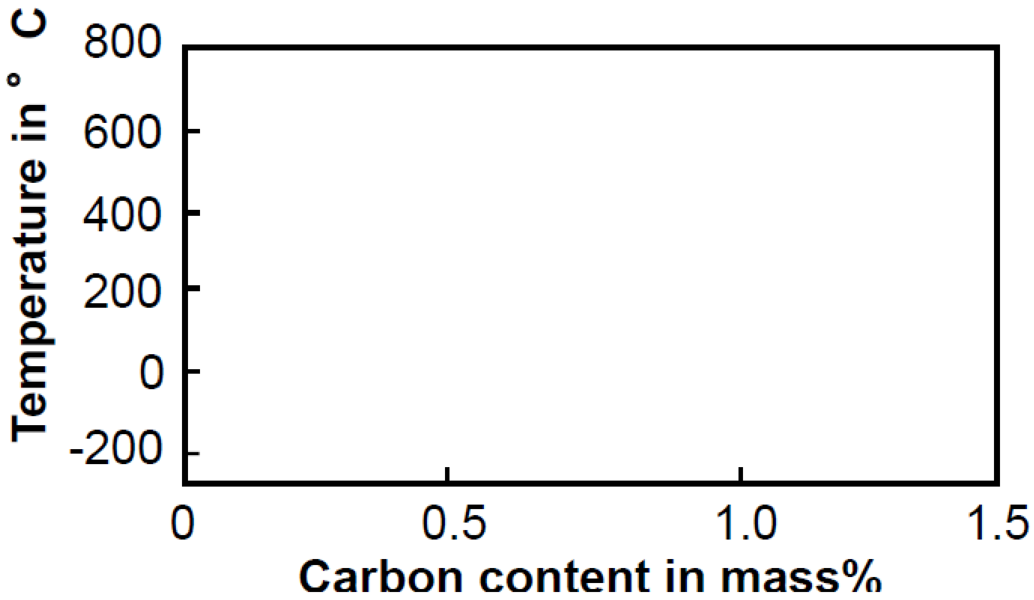
b) Sketch the influence of the Carbon content on the martensite start temperature (M_s) and martensite finish temperature (M_f) in **Figure 2** (2 Points).

Figure 2



c) From Figure 2 in (b), decide the critical carbon content (w_C) with which M_f becomes 25°C. Consider two steels: i) one containing carbon larger than w_C, ii) the other containing carbon equal to w_C. Both steels are fully austenitised and quenched to room temperature afterwards. Compare the resulting hardness and explain the difference based on the microstructure (2 Points).

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