Advanced Metallurgy – Exercise 2 – 24/09/2025

1) Heat treatment of steels

You have been recently hired by a renowned manufacturer of high-precision machine tools and you are responsible for the selection, heat treatment and characterization of the metallic materials used in the production.

a) You have to characterize three different carbon steels, containing 0.3 wt.% C, 0.76 wt.% C and 1.2 wt.% C, which are heat-treated at 800 °C. Are they hypo- or hypereutectoid according to the binary Fe-C phase diagram shown in Figure 1? What phases will result after quenching?

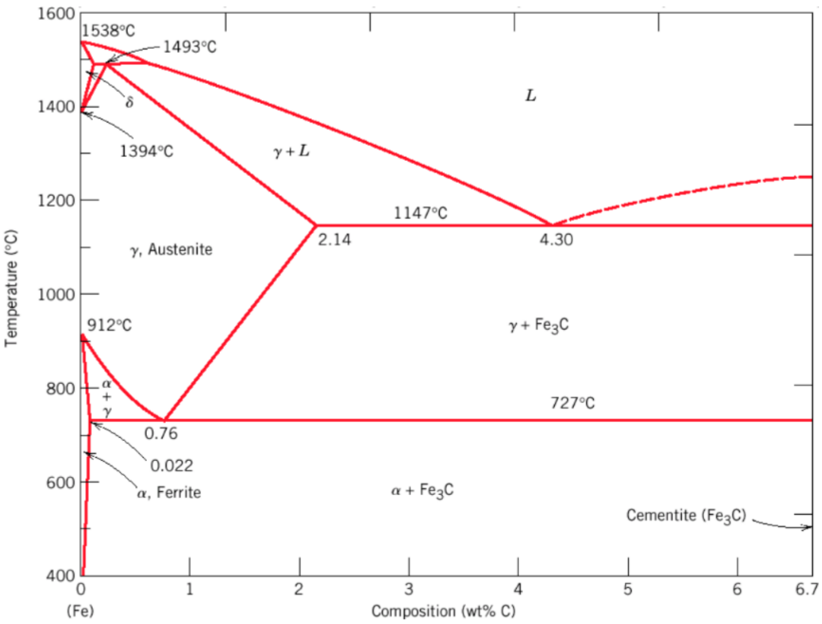

Figure 1: Fe-C phase diagram

b) A colleague has prepared metallographic cross-sections of two other carbon steels and has taken some images with the optical microscope (Figure 2). However, she does not remember the carbon content. Can you help her to estimate the carbon content and label the phases (Tip 1: Ferrite contains 0.02 wt.% C, perlite contains 0.8 wt.% C. Tip 2: Use the area fractions…)?

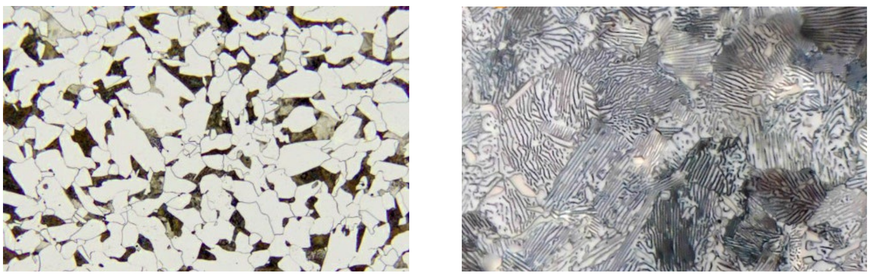

Figure 2: Metallographic cross-sections

Your next job is to decide for a heat treatment cycle for a batch of forged shafts (l = 250 mm, ⌀ 35 mm) made from a low alloyed 30NiCrMo12-6 steel. You know that you have to austenize it first, followed by quenching in oil and subsequent tempering. Your colleague gives you the time-temperature-transformation (TTT) diagram for the steel, shown in Figure 3.

c) Explain the meaning of all lines and fields in the TTT diagram.

d) How can you tell that the steel is hypo- or hypereutectoid from only the TTT diagram? Can you give the chemical composition?

e) From Figure 3, can we determine what phases form for the processing routes labeled 1 and 2? If so, try to estimate the final phase composition.

f) For your steel, you know that an additional tempering step follows immediately on the previously conducted hardening. Would you rather choose a temperature of 200 °C or of 550 °C? Explain your choice. What is the effect of Mo and Cr with regard to an increase in strength at this temperature? Why temperatures around 300 °C and 500 °C typically have to be avoided when tempering steels?

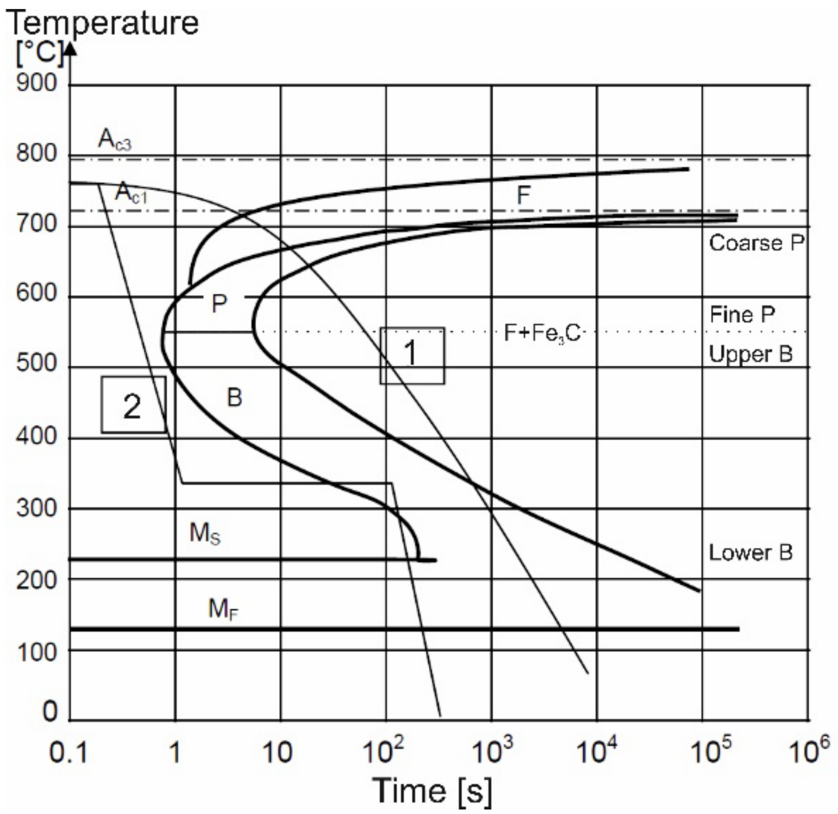

Figure 3: TTT diagram

2) Stainless steels

Your job is to decide for a steel for the door of an industrial heat treatment furnace, used for ceramic dishes production, which is stable for temperatures up to 1100 °C. As the customer is happy to have an expert with him, he moreover asks you what would be your choice for the production of his premium kitchen knife selection.

a) Decide for a material for from Table 1 for both the door and the knives and explain your choice based on the chemical composition and the requirement specifications.

b) As you know, stainless steels are grouped according to their microstructure/alloying concept. Note the corresponding alloying concept from the materials in Table 1 for each composition (tip: The Schaeffler diagram in Figure 4 might give you hints). Moreover, give the name according to the nomenclature.

Table 1: Chemical compositions of different steels

Alloying concept	C	Cr	Mo	Ni	N	Cu	Others
	0.02	25.0	4.0	7.0	0.1-0.2	0.5-1.0	W: 0.5-1.0
	0.06	17.0	2.0	12.0	0.0-0.1	-	Ti/Nb: 5/10 x C
	0.46	13.0	-	-	-	-	Si, Mn: 0.0-1.0
	0.02	12.0	-	-	-	-	Ti: 0.3
	0.12	16.0	-	36.0	0.0-0.1	-	Si, Al: 0.5-2.0

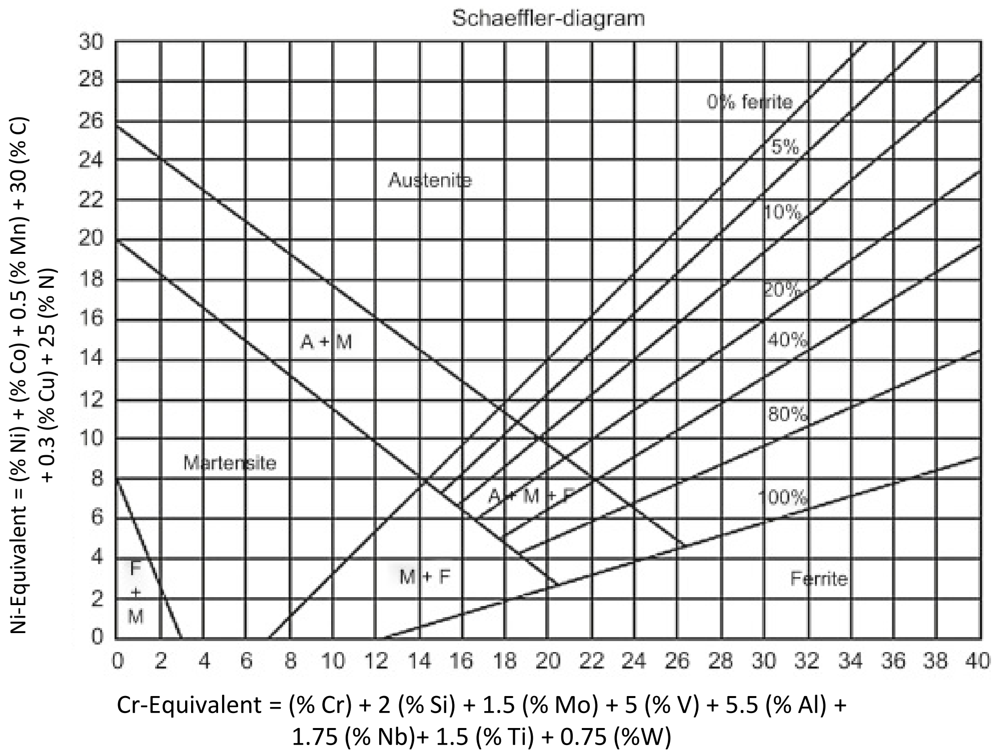

Figure 4: Schaeffler-De Long diagram

3) Advanced High Strength Steels (AHSS)

As a materials engineer in automotive engineering, you know that in recent years multiphase AHSS have been increasingly used for structural parts in car body engineering. Based on their development time, a differentiation is made between 1st, 2nd and 3rd generation AHSS.

AHSS steels of the first generation are, for example, DP, PM, CP and TRIP steels. The latter contain up to 4 wt.% Mn. The special properties of such TRIP steels are based on the presence of about 10-25 vol.% retained austenite.

a) Name three advantages that TRIP steels offer over other 1st generation AHSS in terms of formability and crash safety in car bodies. What is the reason for their high strength? What phases are present?

b) Figure 6 shows processing routes for the production of two different AHSS grades of the first generation, which have almost the same chemical composition, but different phases after heat treatment. Match the steel grades and indicate the predominant phases in the pie chart.

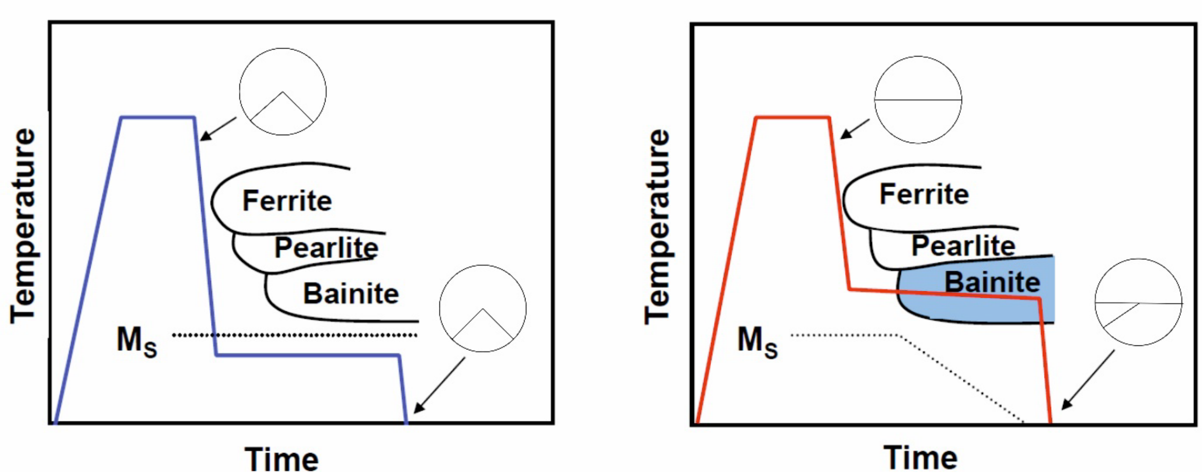

Figure 6: Processing routes of different steel grades of the 1st generation AHSS

c) A cold-rolled side impact bar made from TRIP steel, containing 0.2 wt.% C, is intercritically annealed in the two-phase region between Ac1 and Ac3. After quenching from the austenitic region, which should typically lead to a martensitic microstructure, retained austenite is found in the TRIP steel. Explain how it is possible for there to be any retained austenite at all in a steel with 0.2 mass % carbon. What is meant by "partitioning" in this context? Is this retained austenite thermodynamically stable? Is this retained austenite mechanically stable?

d) Based on your background knowledge, you suggest it would be better to use a second generation (e.g. TWIP steels) instead of the first generation AHSS from c). Draw a schematic diagram of the heat treatment for TWIP steels in the graphic below and name the phase fractions present after each heat treatment step in a pie chart (in a similar way as Figure 6). What are the advantages of TWIP steels in terms of formability, crash safety, and durability compared to TRIP steels?

4) Steels for elevated temperature applications

After your studies at EPFL, you find a position as materials expert with a global mechanical engineering supplier. Customers come from a wide range of industries, which is why your expertise is often required.

a) For some steels, the designation was accidentally deleted from the material database of your company and your help is needed. Name the steels using the rules for nomenclature based on their chemical composition (in wt.%) in Table 2

Name	C	Cr	Ni	Mo	Al	Ti
	0.42	1.00	0.00	0.15	0.00	0.00
	0.36	1.00	1.00	0.15	0.00	0.00
	0.20	12.00	0.10	0.00	0.00	0.00
	0.05	20.00	31.00	0.00	0.05	0.10

b) An automotive supplier is looking for a heat-resistant stainless steel for an exhaust gas system, which is exposed to hot gases with temperatures up to 400 °C during operation. He asks for the best available material you can offer, as his customer is a premium car manufacturer.

- Name a suitable stainless steel from Table 2 and justify your decision in terms of creep resistance

- Why can the strength of the two stainless steels in Table 1 **not** be increased by heat treatment?

- How could the strength of these steels be increased instead?

The solutions of this exercise will be available on Moodle from next exercise session.

Please contact us if you spot any errors or have questions:

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