

Master examination
„Materials Science of Steel“

30.03.2017

Name, first name:

Matriculation number:

Declaration: I am healthy and able to take part in the examination.

Signature:

Task	Points:	Achieved Points:	Points after review (additional points)
1	6		
2	7		
3	7.5		
4	3		
5	10		
6	7.5		
7	5		
8	10		
9	8		
10	8.5		
11	3		
12	6		
13	9.5		
14	2		
15	3		
16	4		
Sum	100		

You need 44% to pass the examination.

Task 1**Tensile testing I****6 Point(s)**

Explain the following characteristic values determined from tensile tests, briefly.
(6 Points)

i) R_{eH} ,

ii) R_{eL} ,

iii) R_m

iv) $R_{p0,01}$

v) n-value

vi) r-value

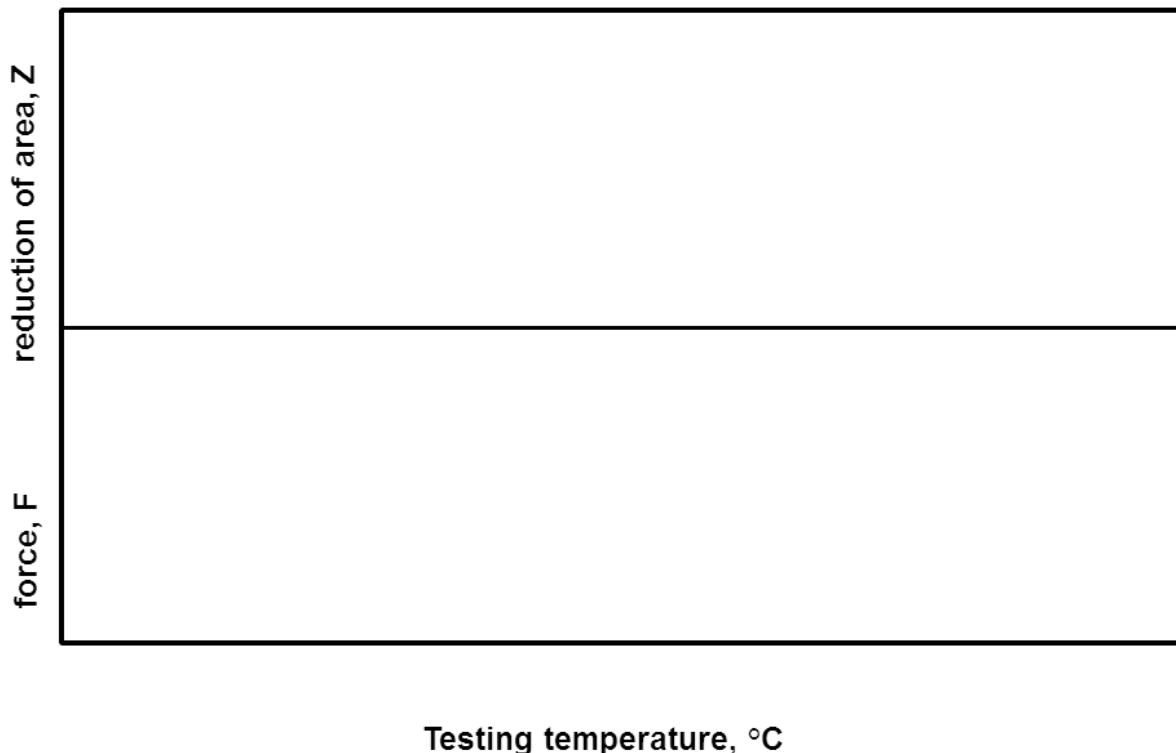
Task 2**Tensile testing II****7 Point(s)**

- a) Sketch the stress-strain-curve for an IF-steel (Steel without solute interstitial atoms) and label the characteristic values. Furthermore, indicate the regions of homogenous and inhomogenous deformation. (4,5 Points)
- b) What is the maximum load that can be applied on a specimen before permanent deformation occurs? What is characteristic for this load? (2,5 Points)

Task 3**Hot tensile test****7.5 Point(s)**

The high temperature behaviour during continuous casting of steel can be described by high temperature tensile tests.

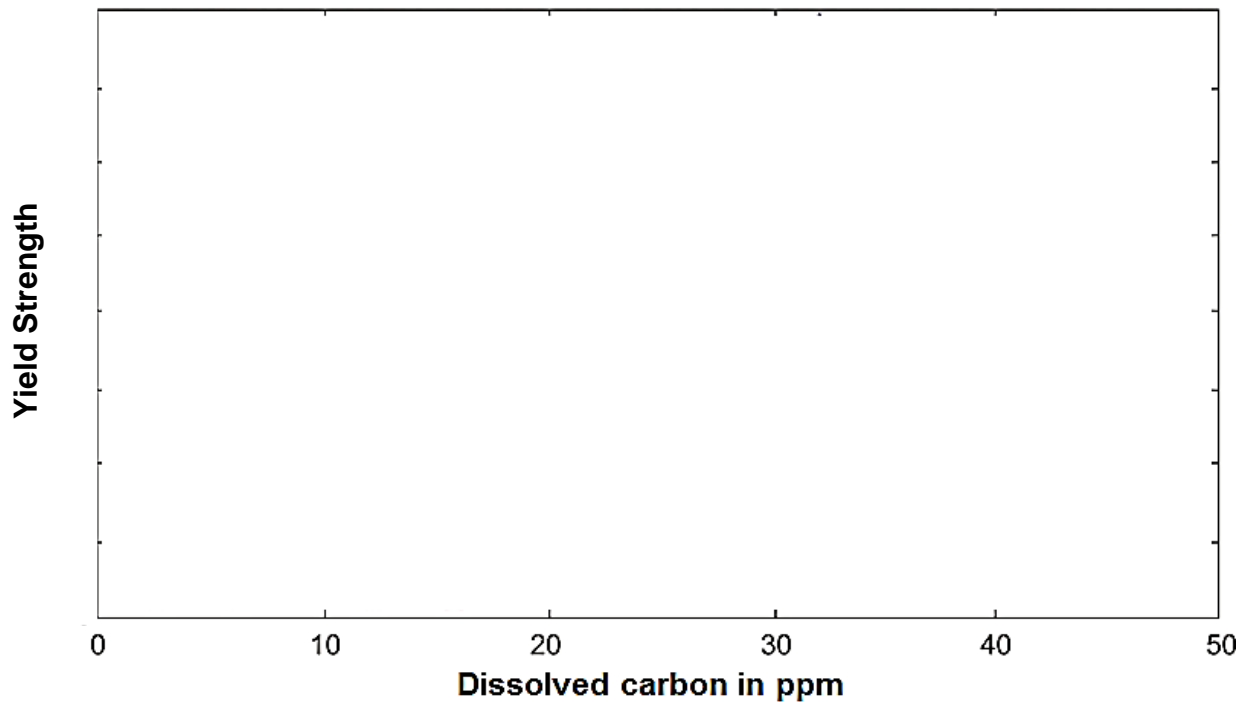
- a) Define the zero ductility temperature (T_{ZD}), the zero strength temperature (T_{ZS}) and the hot crack tendency in the temperature interval (ΔT_0). (3 Points)
- b) Sketch the correlation between the reduction of area and the force during solidification of steels in the continuous casting process with the help of the diagrams in Appendix 1 for a temperature region ranging from 800°C to T_{liq} . (4.5 Points)

Appendix 1

Task 4**Bake-hardening****3 Point(s)**

Sketch the influence of dissolved carbon in ferrite on the yield strength for the following two heat treatments in **Appendix 1**.

- 2% deformation and annealing at 170°C for 20 minutes (bake-hardening) (1 Point)
- annealing at 100°C for 2 hours (artificial aging) (1 Point)

Appendix 1

- State the definition to calculate the bake-hardening-effect. (1 Point)

BH₂= [in MPa]

Task 5 **Strengthening mechanisms** **10 Point(s)**

- a) It is possible to increase the strength of steel by using various strengthening mechanisms. Complete the **Table 1** by indicating the approximate proportionality for the strength increase for each of the mechanisms. Please also list all the parameters in the equation. (4 Points)

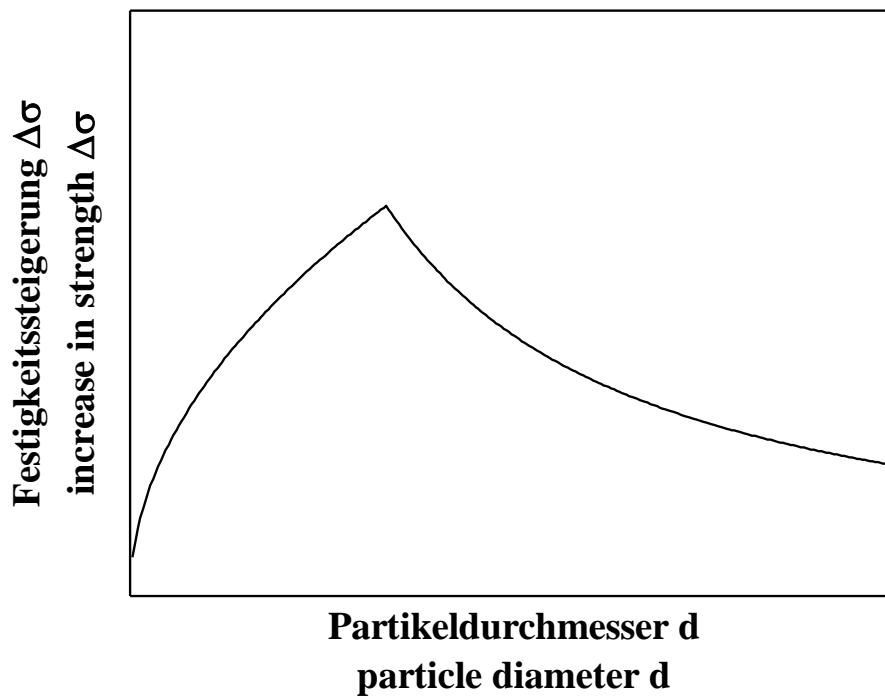
Table 1

No.	Mechanism	Strengthening
1.	Dislocation strengthening	$\sim Gb\rho^{1/2}$ where, G = shear modulus; b = Burger's vector; ρ = dislocation density
2.	Solid solution strengthening	
3.	Grain refinement	
4.	Precipitation strengthening	
5.	Multi-phase strengthening	

- b) Interstitial elements like C and N cause a high increase in the strength of ferrite in steels, even when added in very small amounts. However, to cause a similar increase in the strength of austenite, much higher amounts of C and N are necessary. Why is that so? Explain briefly. (1 Point)
- c) Martensite is a unique transformation product in steel, in which several strengthening mechanisms are active simultaneously. Name at least three strengthening mechanisms in Fe-C martensite. (3 Points)

- d) Precipitation strengthening is a strengthening mechanism, often used in steels. In this method, particles of a certain size range are used to increase the strength of steel. Explain the influence of the precipitate size (particle size) on the strength increase of steels which can be seen in **figure 1**. Name the interaction mechanisms before and after the peak (maximum strength increase). What is the approximate precipitation size to obtain the maximum strength increase? (2 Points)

Figure 1



Vanadium and Niobium can form carbonitrides of type $M(C,N)$.

- d) Are these Elements dissolved or precipitated after reheating to a temperature of 1250°C? (0.5 Points)

Task 7**Fracture mechanisms****5 Point(s)**

The fracture mechanisms of bcc steels are temperature dependent.

- a) Sketch a stress-temperature-diagram, which can be used to show the switch from ductile to brittle fracture behaviour of bcc-steels. (3 Points)

- b) Describe the microscopic appearance of the fracture surface at high and low temperatures, respectively. (2 Points)

Task 8**Charpy impact tests****10 Point(s)**

Charpy impact tests can be used to characterize the toughness of steels.

- a) Explain the standard charpy impact test (without additional instrumentation). Consider the specimen geometry, measuring technique and further boundary conditions (2 Points).
- b) How can you measure the impact energy for a standard charpy impact test? How can you evaluate the impact energy for an “instrumented charpy impact test”? (4 Points)

- c) Sketch the measured curves from an “instrumented charpy impact test” for a very brittle and a very ductile steel in one diagram. Label the axes. (4 Points)

Task 9**Fracture mechanics****8 Point(s)**

A construction steel S460 is used to manufacture a SENB 10x20 specimen as can be seen in figure 1. The specimen is prepared according to ASTM E 399 and BS 5762 standards. The testing temperature is -95 °C. Brittle fracture is observed after testing.

- How long is the required crack in the SENB 10x20 specimen according to the standards before testing? Your answer can either be a crack length in mm or the ratio of crack length/ specimen width. Explain why a fatigue pre-crack is applied to the specimen before the actual testing? (2 Points)
- Indicate the point which is necessary to determine the fracture force in figure 2. (2 Points)
- Calculate the K_Q value. Consider the given equations. The value of the correction function $f(\lambda)$ corresponds to 2,66 in this case. State the calculated K_Q value in in $\text{MPa}\cdot\text{m}^{1/2}$ as well as in $\text{N}/\text{mm}^{3/2}$. (4 Points)

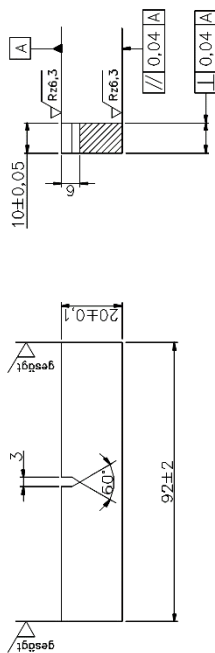


Figure 1: Sketch of SENB 10x20 specimen

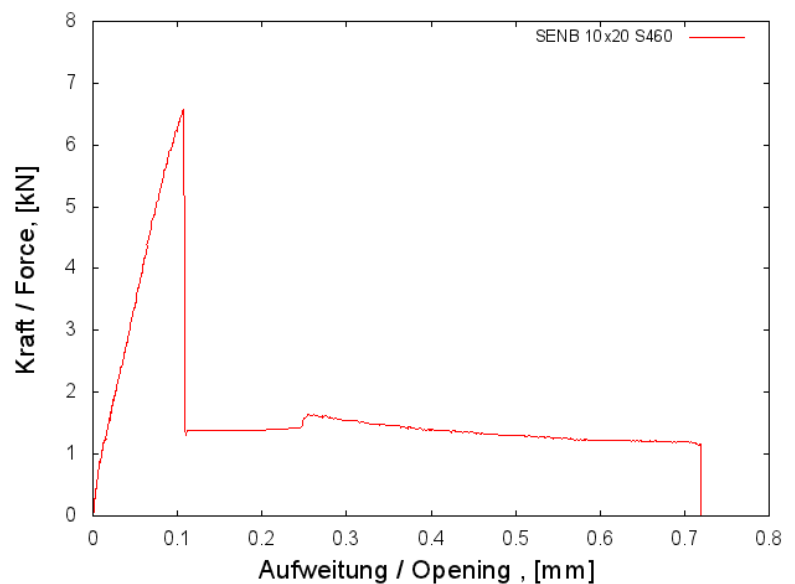


Figure 2: Force - Crack tip opening displacement data from experiment

$$K_Q = \frac{FS}{BW^{3/2}} f(\lambda)$$

$$\lambda = \frac{a}{W}$$

$$W=2B$$

$$S=4W$$

Task 10**Fatigue testing****8.5 Point(s)**

The fatigue behaviour of metallic materials is commonly described using S-N curves, also known as Wöhler curves.

- a) Sketch a sinusoidal stress-time-curve with exactly two cycles. Mark the following characteristic values (σ_m , σ_a , σ_U and σ_L). (3,5 Points)
- b) Sketch the sinusoidal stress-time-curve for the stress ratios $R=0$ and $R=-1$. Furthermore, state the equation to calculate the stress ratio R . (2 Points)

- c) A nonlinear correlation occurs in the elastic-plastic region for specimens manufactured without notch. Sketch a stabilized hysteresis loop and a cyclic stress-strain curve. How can the cyclic stress-strain curve be determined?
(3 Points)

Task 11**Bauschinger-effect****3 Point(s)**

- a) What is the “Bauschinger-effect” and what is the reason for this effect? (2 Point)
- b) What can be done to minimize this effect? (1 Point)

Task 12**Sheet testing I****6 Point(s)**

- a) Correlate one sheet testing methods for each of the following strain states of a Forming Limit Diagram (FLD). (4 Points)

$$\varepsilon_1 = -\varepsilon_2$$

$$\varepsilon_1 = -2\varepsilon_2$$

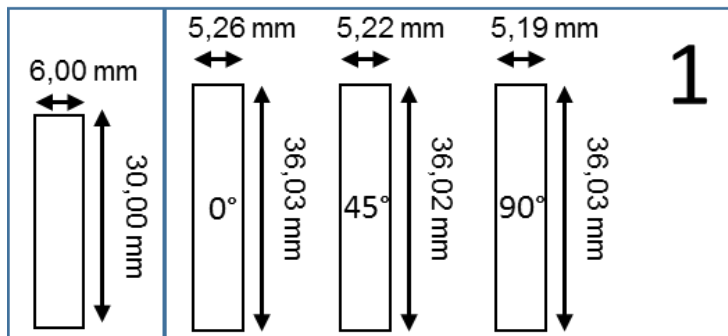
$$\varepsilon_1 = -\varepsilon_3,$$

$$\varepsilon_1 = \varepsilon_2$$

- b) How is the hole expansion ratio λ be determined? State the required equation and explain all necessary parameters. (2 Points)

Task 13**Sheet testing II****9.5 Point(s)**

Tensile tests have been performed on A₃₀ flat tensile test specimens. The gauge length and the width of the specimen has been measured before and after testing. The determined values are given in **Appendix 1**.

Appendix 1

- a) Calculate the logarithmic strain in all three directions for all three experiments based on the values from Appendix 1. State the required equations. (2.5 Points)
- b) Calculate the vertical anisotropy for material 1 and state the required equation. (1.5 Points)

- c) The testing direction of the specimens was longitudinal (0°), transverse (90°) and diagonal (45°) to the rolling direction as indicated in appendix 1. Calculate the mean and the planar anisotropy and state the required equations. (3 Points)
- d) Which two conclusions according to the formability can be drawn for the mean and planar anisotropy? (1.5 Points)

- e) Two additional materials have been tested. The determined mean and planar anisotropy for these materials are summarized in appendix 2. Which material is the most suitable for deep drawing? Explain your answer briefly. (1 Point)

Appendix 2

		Mittlere Anisotropie Mean anisotropy	planare anisotropie planar anisotropy
Material 2		0.9	0.25
Material 3		1.6	0.1

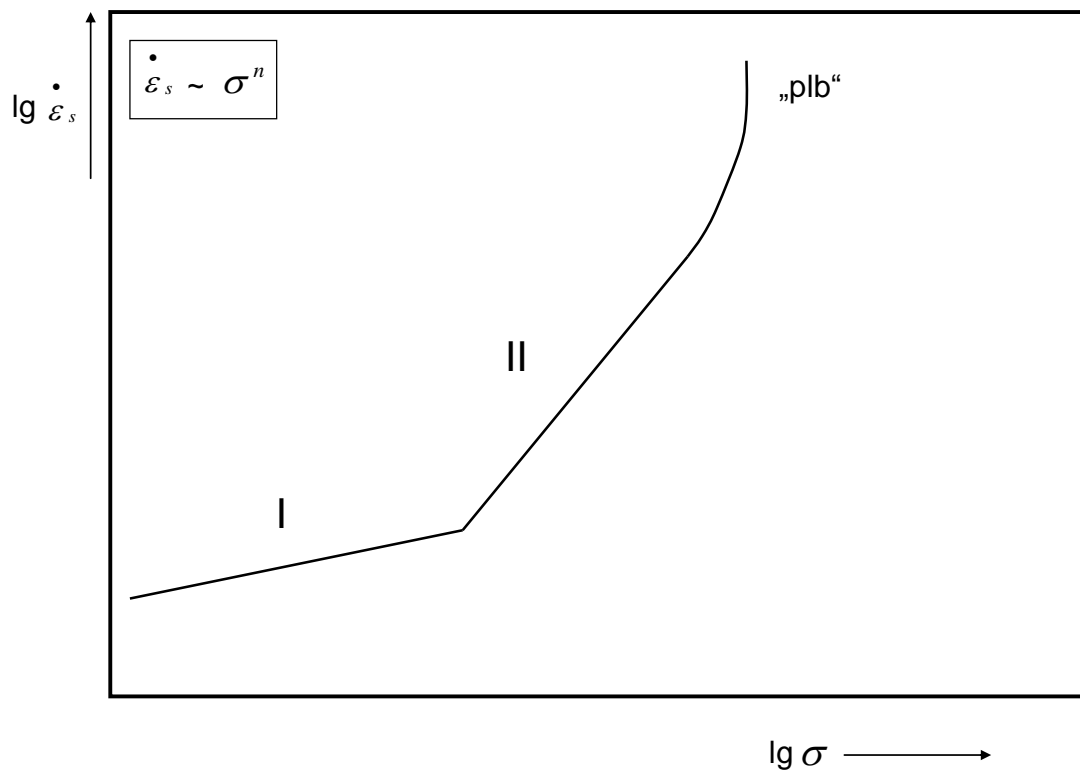
Task 14**High temperature properties****2 Point(s)**

The mechanical properties of steels have a high strain rate dependence at high temperatures. A strain rate – stress-curve is shown in the following diagram.

Indicate the strain rate – stress curve for a material with

- a larger grain size (1 Point) and
- a lower Young's modulus (1 Point)

in the given diagram.



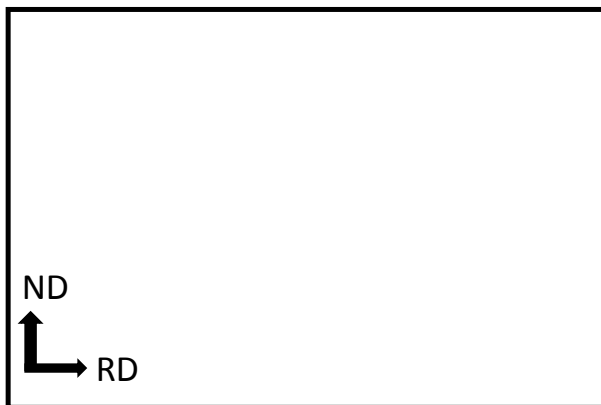
Task 15**Metallography****3 Point(s)**

Metallography is used to get important knowledge about non-metallic inclusions in steels.

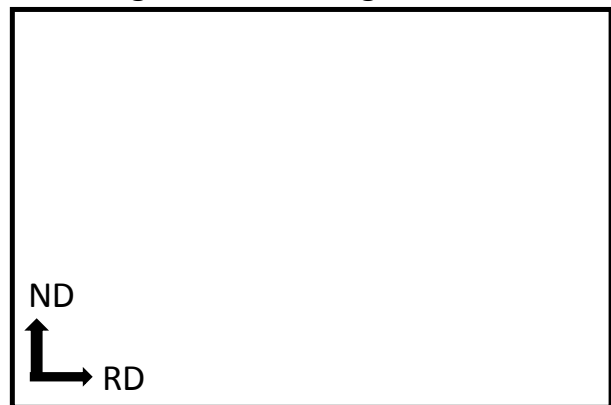
Explain the characteristics of Manganese sulfide and Aluminium oxide after cold rolling steels. Therefore, sketch the above mentioned inclusions after cold rolling in the figures in Appendix 1 and explain the shape of the inclusions. (3 Points)

Appendix 1

Aluminiumoxid / Aluminium oxide



Mangansulfid/ Manganese sulfide



ND: normal direction / Blech Normalenrichtung

RD: rolling direction / Walzrichtung

Task 16**Electron microscopy****4 Point(s)**

- a) What reactions can occur when electrons penetrate the sample surface? Name and describe three kinds of radiations occurring the penetration of electrons on the surface of the specimen. (3 Points)
- b) Explain the differences in the specimen preparation for SEM and TEM investigations resulting from the measuring principle of each electron microscope. (1 Point)