

Master examination
„Materials Science of Steel“

31.08.2015

Name:

Matriculation number:

Signature:

Task	Points:	Points achieved:	Points after review (additional Points)
1	6		
2	4		
3	7		
4	4,5		
5	10		
6	6,5		
7	10		
8	11		
9	3		
10	6		
11	8		
12	5		
13	8		
14	5		
15	4		
16	2		
Sum	100		

You need 44% to pass the examination. The examination is divided into three parts which have to be passed separately. The final result is calculated as follows:

37.5 % Written examination (“Materials Science of Steel”)

37.5 % Oral Examination (separate date)

25 % Written examination (“Materials Science of Steel –Steel Design”)

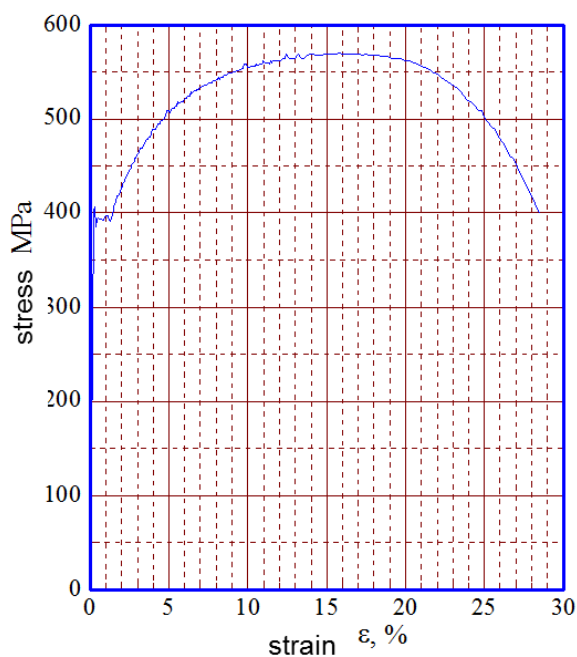
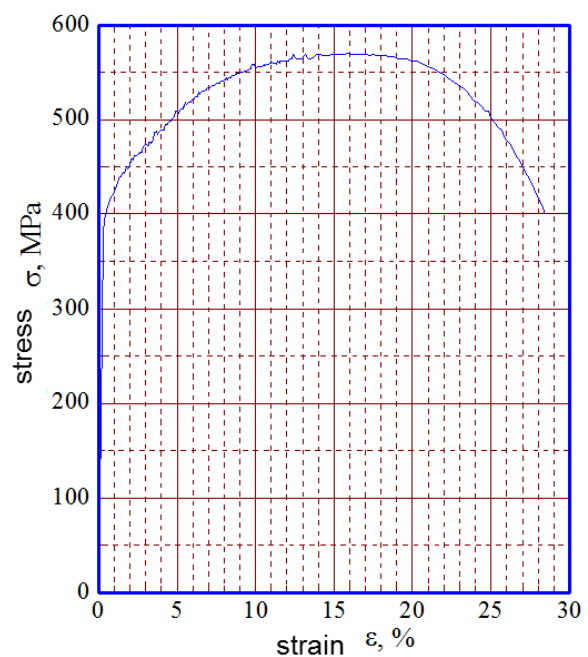
Task 1**Tensile test I****6 Point(s)**

Give a short explanation for the following values which have been determined from tensile tests. (6 Points)

- i) R_{eH} ,
- ii) R_{eL} ,
- iii) R_m
- iv) $R_{p\,0,01}$.
- v) n-value
- vi) r-value

Task 2**Tensile test II****4 Point(s)**

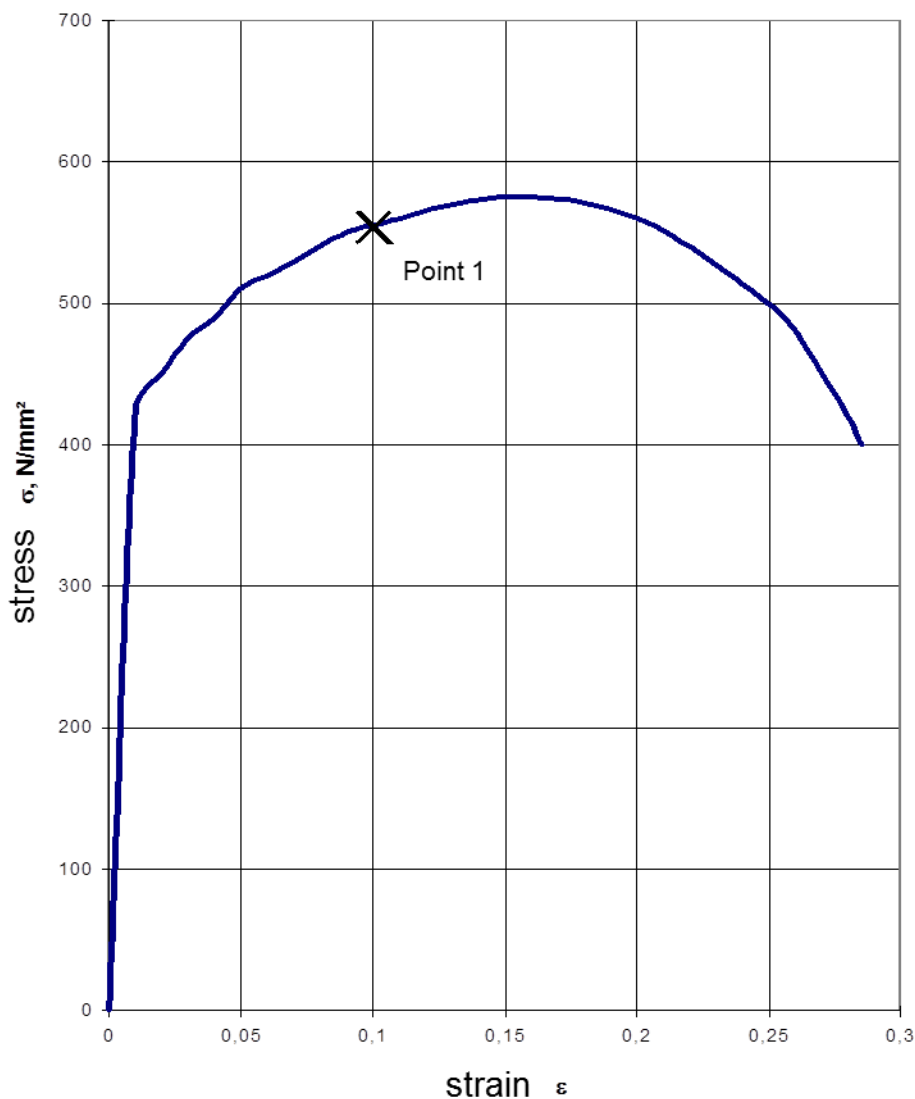
- a) Two different stress-strain diagrams for a steel with different processing treatments can be seen in **Appendix 1**. Which processing treatment is the reason for the different stress-strain diagrams? Explain how this processing treatment influences the flow curve. (Consider the strength levels of both diagrams). (2 Points)
- b) Indicate the points of characteristic values of mechanical properties (stress and strain values) in both diagrams. (2 Points)

Appendix 1**Processing A****Processing B**

Task 3**True stress-strain diagram****7 Point(s)**

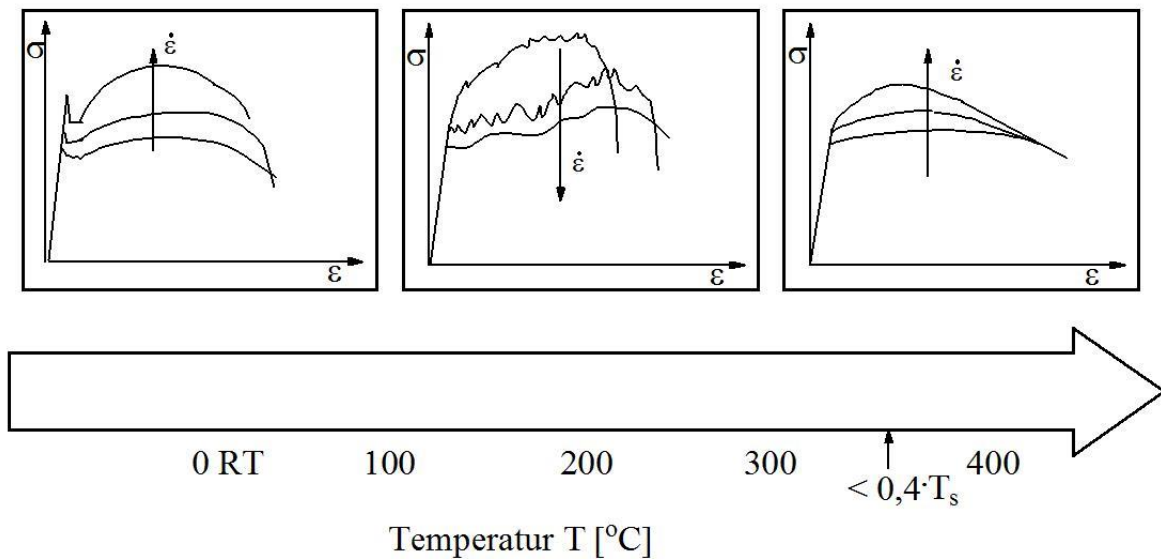
A true stress-strain diagram can be seen in Appendix 1.

- Calculate the true strain and the true stress for Point 1 given in Appendix 1. Furthermore plot the point with the true stress and strain values in the given Diagram in Appendix 1. (5 Points)
- Sketch the true stress-strain curve based on the stress-strain curve given in Appendix 1. Which region cannot be considered for the transformation of stress-strain to true stress-strain curves? (2 Points)

Appendix 1:

Task 4**Strain rate dependency****4,5 Point(s)**

The flow characteristics strongly depend on temperature and strain rate. Please fill in the characteristic temperature ranges for the three different stress-strain-diagrams in the figure (temperature arrow) in **Appendix 1**. Please describe the characteristic phenomena of each temperature range and explain the reasons for the different strain rate dependencies, briefly. (4.5 Points)

Appendix 1

Task 5**Strengthening of Steel****10 Point(s)**

- a) Name at least 3 substitutional alloying elements, which increase the Yield strength of bcc-steels and arrange the alloying elements according their relative effectiveness. (3 Points)
- b) Grain refinement is another approach to strengthen steels besides solution strengthening. Give the empirical equation which is used to calculate the Yield strength of steels based on the grain size and explain all parameters which are necessary for this equation. (3 Points)

- c) Depending on their size carbides and nitrides lead to grain refinement or precipitation strengthening. What is the size of precipitations which lead to grain refinement or precipitation strengthening? (2 Points)
- d) What is the effect of precipitation strengthening, dislocation strengthening, solution strengthening and grain refinement on the toughness (measured based on the transition temperature of steels)? (2 Points)

Task 6 **Thermo mechanical processing** **6,5 Point(s)**

- a) How do microalloying elements affect the microstructural changes during hot rolling of steel? (3 Points)
- b) A steel which has been thermomechanical treated has a maximum in hardness after coiling at 600°C. Explain the maximum of hardness. How would a higher/lower coiling temperature affect hardness of this steel? (2 Points)
- c) Name three micro alloying elements which are used for thermo-mechanical treated steels (1.5 Points)

Task 7**Sheet testing****10 Point(s)**

The phenomenon of steel aging is applied targetedly for the bake-hardening-effect.

- a) Explain the bake-hardening-effect. Consider the initial microstructure for your explanation. Furthermore declare the observed stress-strain-curve. (6 Points)
- b) Define conventional process parameters by means of time and temperature for the bake-hardening-treatment and name one industrial process step and one industrial component this treatment is used for! (2 Points)

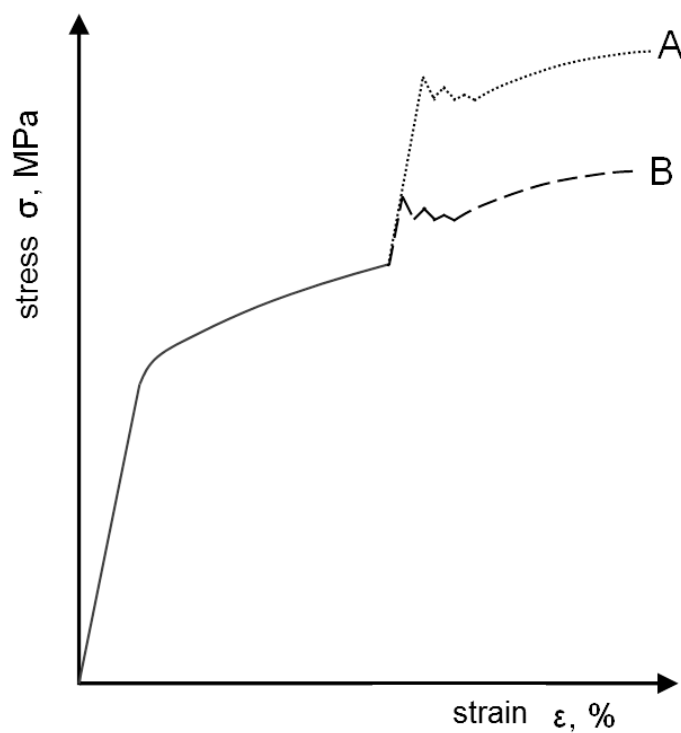
c) Specimens of a car body steel have been processed using the following different parameters:

a) 185 °C for 10 minutes

b) 250 °C for 1000 minutes

The schematic stress-strain curves after each treatment can be seen in **Appendix 1**. Correlate the stress-strain curves with the treatments and explain your choice. (2 Points)

Appendix 1



Task 8**Sheet testing II****11 Point(s)**

Tensile tests with two sheet steels in different directions show the following elongation values ($\varphi_{\text{elongation}} = 0,20$):

Material 1

	$\angle 0^\circ$ to rolling direction	$\angle 45^\circ$ to rolling direction	$\angle 90^\circ$ to rolling direction
φ_w	-0,131	-0,121	-0,136

Material 2

	$\angle 0^\circ$ to rolling direction	$\angle 45^\circ$ to rolling direction	$\angle 90^\circ$ to rolling direction
φ_w	-0,118	-0,119	-0,117

Calculate the perpendicular (r), the average (r_m) and the planar anisotropy (Δr) for both materials and describe the

- deep drawability of the two materials and
- the materials' earing tendency.

Explain your answer. (11 Points)

Task 9**Fracture mechanics****3 Point(s)**

- a) Which idealised material behaviour is needed for the characterisation of the fracture toughness K_{IC} ? Give the unit of K_{IC} . (2 Points)
- b) Sketch a test sample for the determination of K_{IC} . Please consider the specific detail of the notch. (1 Point).

Task 10**Fracture mechanisms****6 Point(s)**

- a) Name the different steps of slip fracture. (3 Points)
- b) Describe briefly the macroscopic fracture appearance of slip- and cleavage fracture. (2 Points)
- c) Explain the difference between transcrystalline and intercrystalline crack configuration (1 Point).

Task 11**Impact testing****8 Point(s)**

Instrumented impact testing using a high strength construction steel (S690Q) using ISO-V-notch specimens (10x10x55 mm³). The impact velocity of the pendulum is 7.72 m/s (impact energy 1471 J, mass of pendulum 49,368 kg). The time-force diagram of the experiment can be seen in **Diagram 1**.

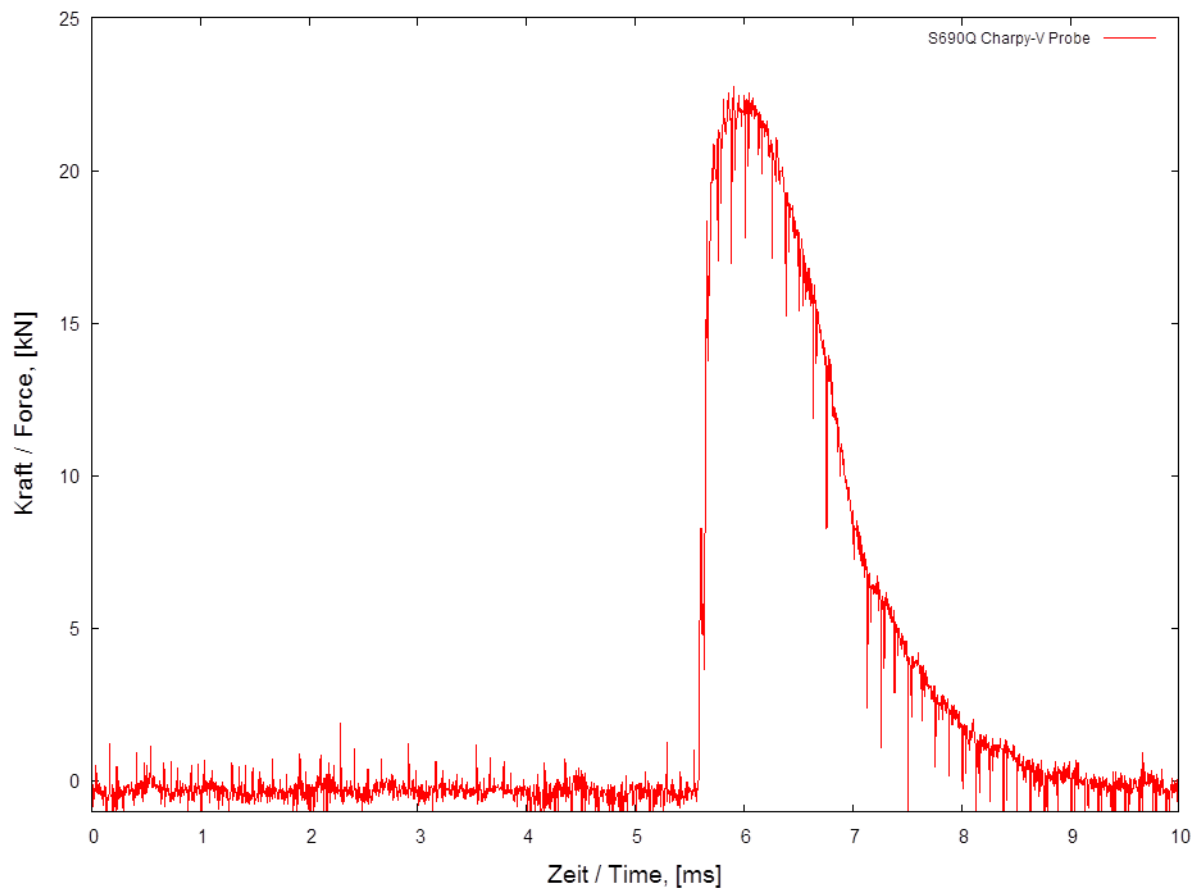


Diagram 1 force-time diagram of an instrumented charpy impact test, steel S690Q, Charpy-V-notch specimen

- a) Which equations are necessary to calculate the notch impact energy based on the force-time-diagram? (2 Points)

- b) Describe qualitatively the pendulum velocity change during the fracture of the sample. Is the energy change relevant when a typical structural steel with an impact energy of ~ 300 J is tested? (2 Points)
- c) Simplify the equations of task a) based on the additional information derived from task b). (2 Points)

- d) Estimate the Charpy impact energy based on the equations from task c). Describe all necessary assumptions which are therefore necessary. (2 Points)

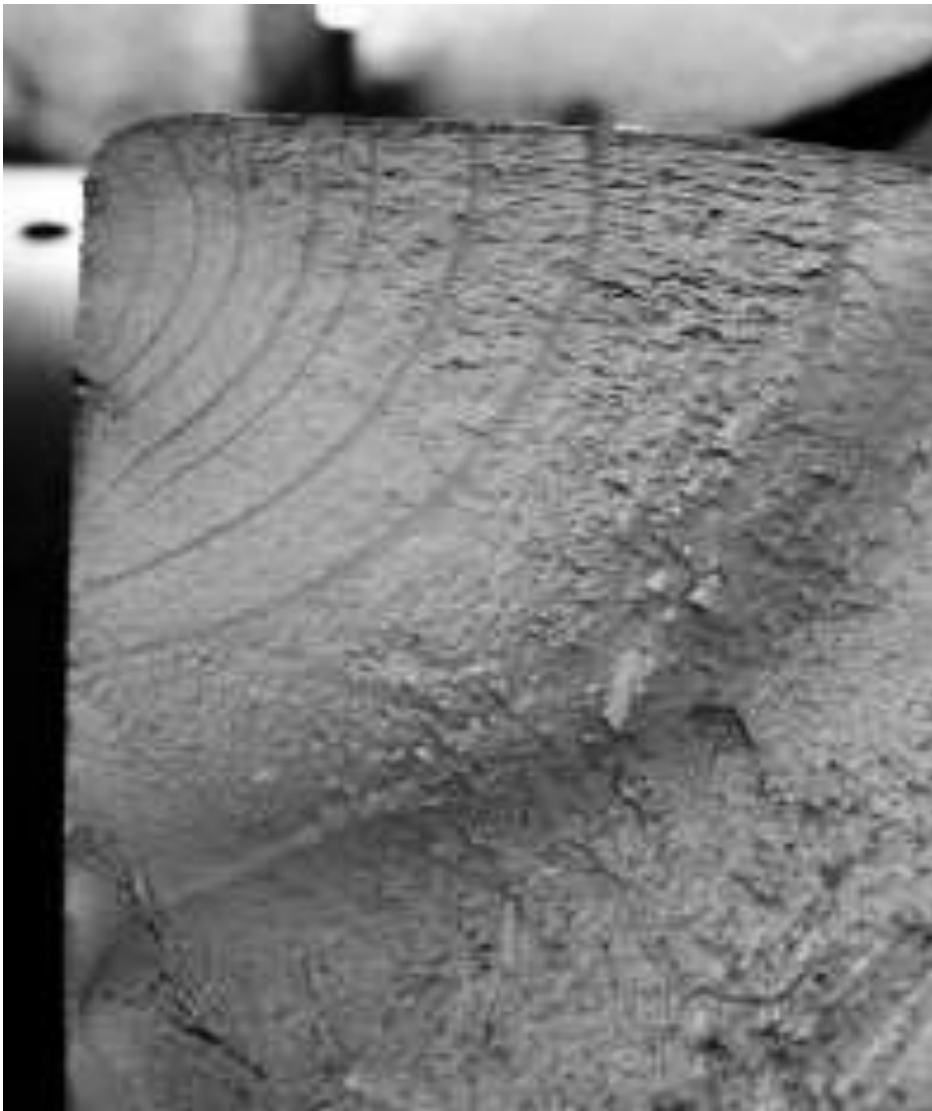
Task 12**Cyclic testing I****5 Point(s)**

The fatigue behavior of steels is determined by S-N curves by constant amplitude.

- a) Sketch a cyclic stress-cycle number curve (“woehler-curve”) and indicate important areas. (3 Points)

- b) **Appendix 1** shows the fracture surface of a component which is broken under cyclic load. Indicate the position where crack formation has started. (1 Point)
- c) What is the name of the characteristic lines which are aligned semicircular? (1 Point)

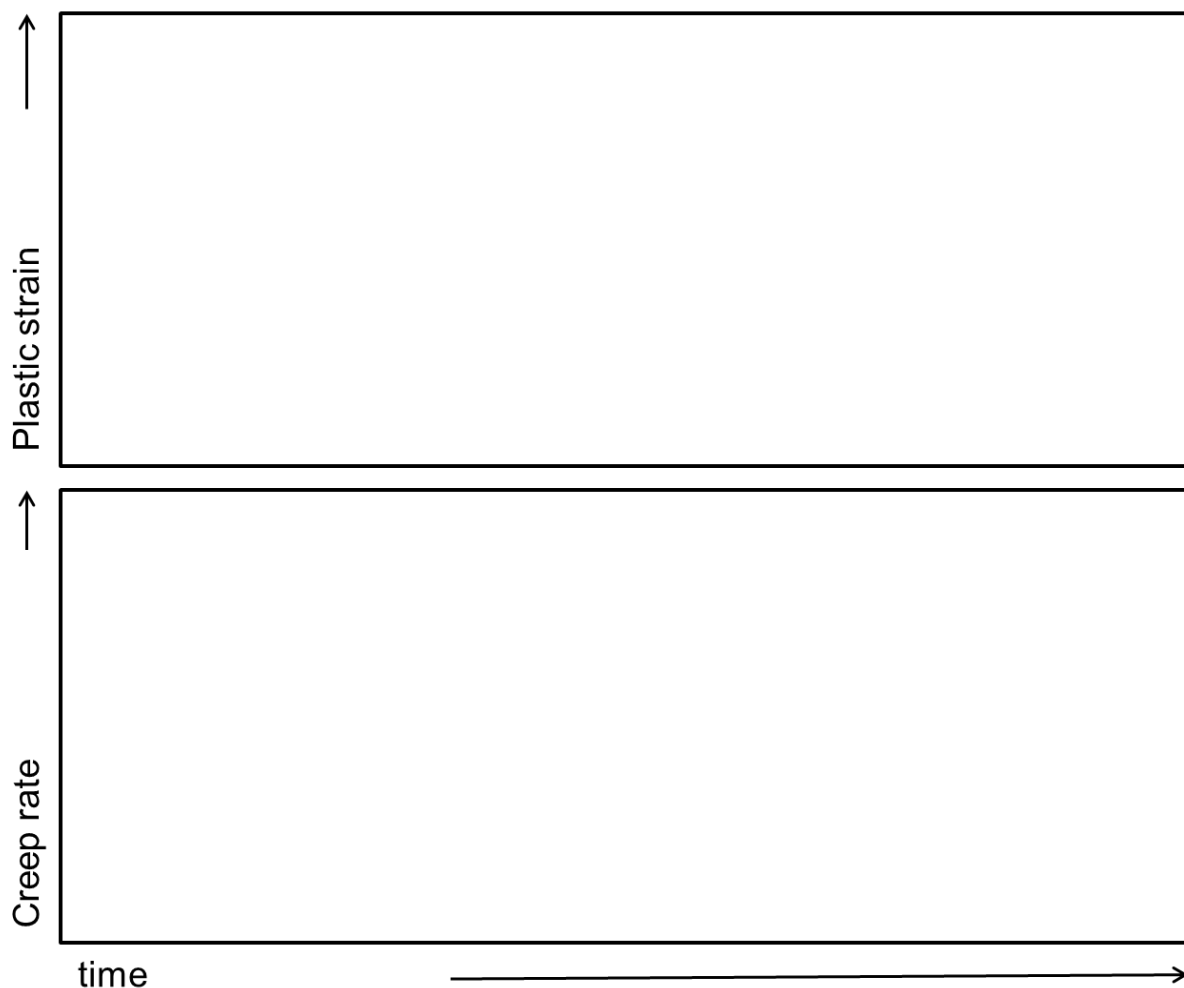
Appendix 1



Task 13**High temperature properties****8 Point(s)**

The high temperature behavior of materials is strongly controlled by diffusion controlled processes.

- a) Sketch the plastic strain- time diagram which can be determined from creep tests in the upper diagram of **Appendix 1**. Furthermore add the areas of i) stationary creep, ii) accelerated creep and iii) transient creep. (2.5 Points)
- b) Sketch the corresponding creep rate in the lower diagram of **Appendix 1**. (1.5 Points)

Appendix 1

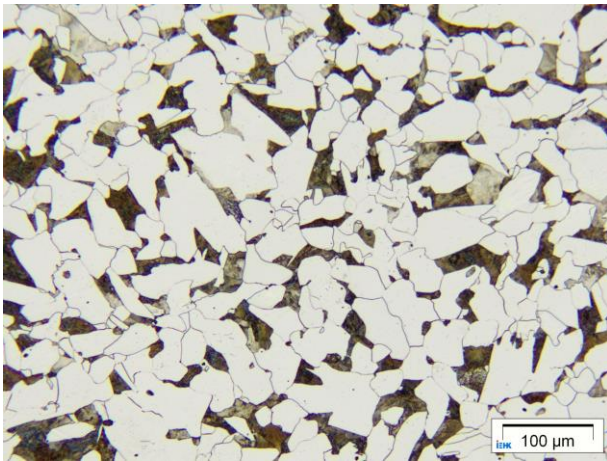
- c) Name 4 metallurgical phenomena which occur during creeping (4 Points)

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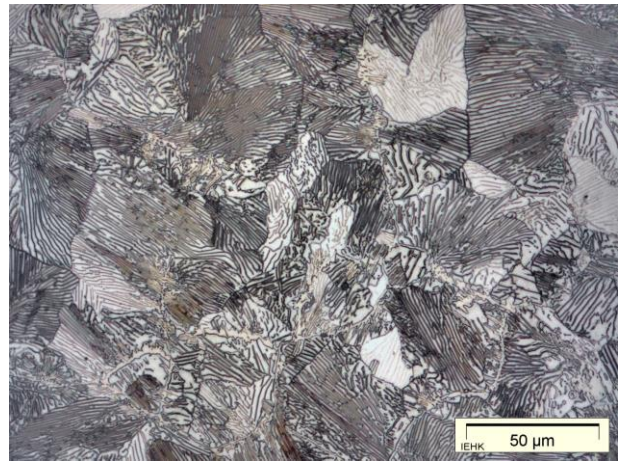
Task 14**Light optical microscopy****5 Point(s)**

Microstructural analysis is commonly carried out using light optical microscopy.

- a) Two different microstructures which have been cooled using near-equilibrium cooling rate can be seen in **Appendix 1**. Name both microstructures and label the different phases of each micrograph. (3 Points)
- b) What is the approximate C content in wt.% for each steel? (2 Point)

Appendix 1

1)



2)

Task 15**Electron microscopy****4 Point(s)**

Name at least 2 advantages and disadvantages of Wavelength-dispersive X-ray spectroscopy (WDS/WDX) and Energy-dispersive X-ray spectroscopy (EDS/EDX). (4 Points)

Task 16**Metallography****2 Point(s)**

What is the microscopic resolution limit for: i) light optical microscopy and ii) transmission electron microscopy? (2 Points)