Master examination

„Materials Science of Steel“

26.03.2015

Name:

Matrikelnumber: **Signature:**

Task	Maximum Points:	Points achieved:	Points after Review (additional Points)
1	5		
2	9		
3	4		
4	10		
5	8		
6	8		
7	5		
8	10		
9	10		
10	8		
11	7		
12	8		
13	8		
Sum	100		

You need 44 % to pass this 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)

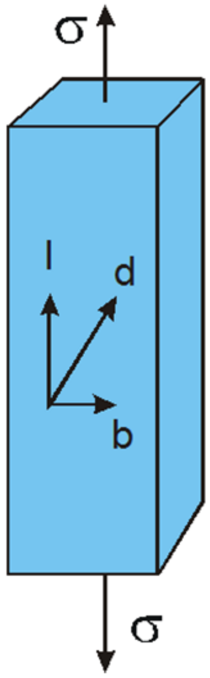
25% % Written examination (“Materials Science of Steel – Steel Design”)

Task 1 tensile test 5 Points

a) What is "anisotropy"? How does it affect the results of tensile tests (1 Point)?

b) Sketch the flow behaviour of the flat tensile specimen given in Appendix 1. Indicate necessary geometries and changes in shape. Furthermore, add the equation to calculate the "verticle anisotropy" (2 Points).

Appendix 1:



c) Specimen of an IF-Steel have been tensile tested. The following values have been determined:

- r = 1.6
- φ_l= 0,5

How much is the true strain in width direction *(2 Points)*?

Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
E-Mail: bleck@iehk.rwth-aachen.de Fax: +49 241 8092224

Task 2 true stress – true strain 9 Points

a) Sketch a conventional stress-strain-curve, a "true stress"-"true strain"-curve and a "true stress"-"true strain"-curve which has been corrected according to "Siebel" (3 Points).

b) Explain the most important differences between the conventional stress-strain-curve and the "true stress"-"true strain"-curve briefly. Give the equations to calculate conventional and true values based on the cross section A_0, initial specimen length l_0 and force F (3 *Points*).

Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
E-Mail: bleck@iehk.rwth-aachen.de Fax: +49 241 8092224

c) Characterize the stress state before and after the uniform elongation A_g. Why is the "true strain"-"true stress"-curve corrected after the uniform elongation (3 Points)?

Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
E-Mail: bleck@iehk.rwth-aachen.de Fax: +49 241 8092224

Task 3 Portevin-Le-Chatelier 4 Points

a) Sketch a conventional stress-strain-curve for a bcc steel at i) room temperature, ii) 120 °C and iii) 500 °c in one diagram (3 Points).

b) Explain briefly the "Portevin-Le-Chatelier"-effect which occurs at 100 °C (1 Point).

Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
E-Mail: bleck@iehk.rwth-aachen.de Fax: +49 241 8092224

Task 4 Considère-criteria 10 Points

"True stress"-"true strain"-curves do not have a maximum force which can be correlated with the beginning of necking. The uniform strain can be calculated using the Considère-criteria.

a) Derive the equation for the Considère-criteria to calculate the uniform strain *(6 Points).*

Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
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b) Sketch the Considère-criteria *(4 Points).*

Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
E-Mail: bleck@iehk.rwth-aachen.de Fax: +49 241 8092224

Task 5 TMB 8 Points

Before hot rolling or hot forging the steel is reheated above the Ac_3-temperature.

a) Sketch the temperature dependency of grain growth for i) a C-Mn steel and 3 steels which are micro alloyed with ii) V, iii) Ti and iv) Nb *(4 Points)*.

b) How do micro alloying elements effect the grain growth? Explain the different grain growth behavior for each of the cases of part a) based on the physical phenomena (*4 Points).*

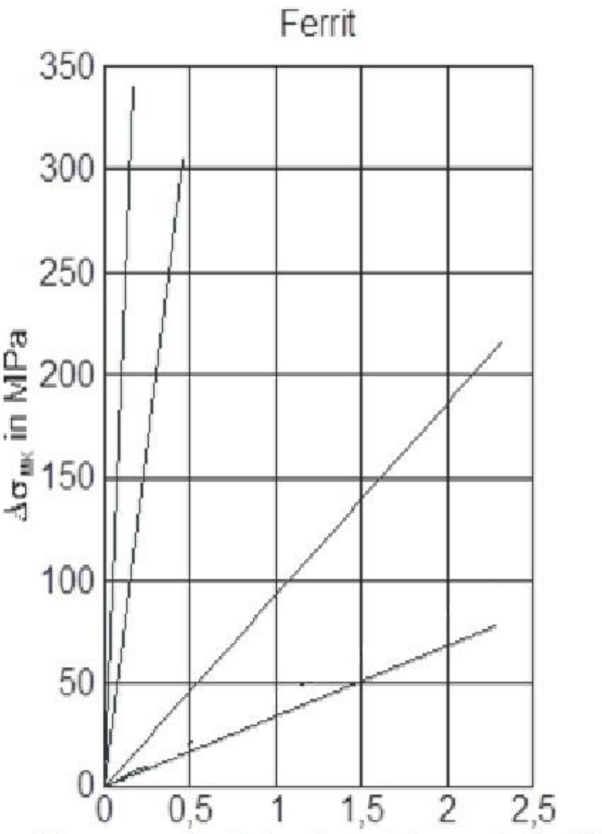
Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
E-Mail: bleck@iehk.rwth-aachen.de Fax: +49 241 8092224

Task 6 strengthening of steel 8 Points

a) The yield strength of steels can be increased by solid solution strengthening. **Appendix 1** shows the effect of content of different alloying elements on the yield strength of ferritic steels. Indicate which line corresponds to the following alloying elements: i) P, ii) Si, iii) C, iv) Mn (4 *Points*).

b) Which alloying element is the most favourable for solid solution strengthening? Which alloying elements should not be used to strengthen steel? Give a short explanation for each alloying element mentioned in task a) (*4 Points*)

Appendix 1:



Alloying conent in wt-%

Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
E-Mail: bleck@iehk.rwth-aachen.de Fax: +49 241 8092224

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E-Mail: bleck@iehk.rwth-aachen.de Fax: +49 241 8092224

Task 7 fracture mechanisms 5 Points

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 test 10 Points

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).

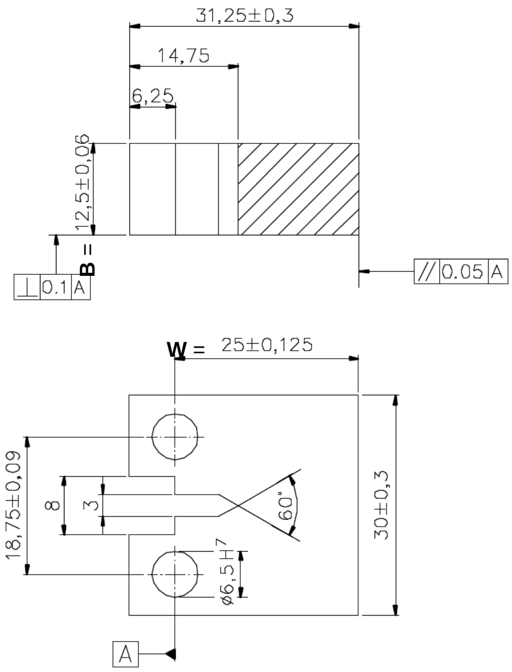
Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
E-Mail: bleck@iehk.rwth-aachen.de Fax: +49 241 8092224

Task 9 fracture mechanic 10 Points

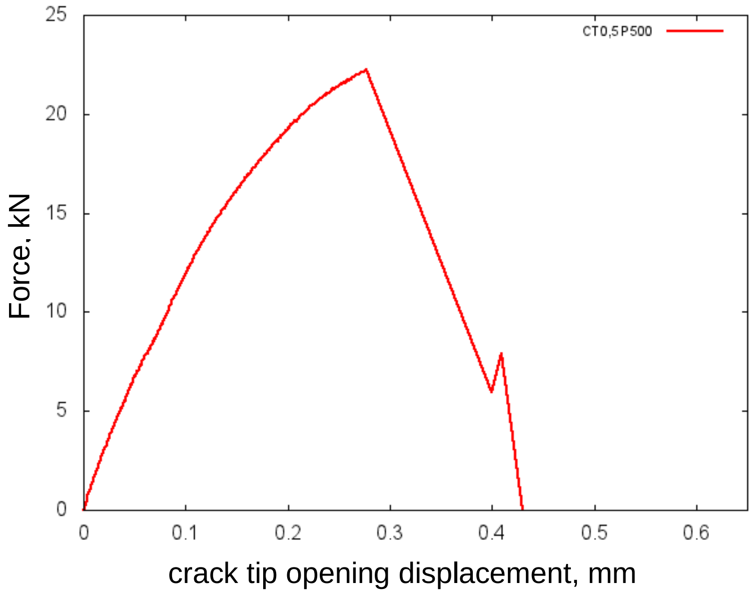
A pressure vessel steel P500 has been tested at -150°C using a CT sample. The sample has been prepared according to ASTM E 399 and BS 5762 standards. Brittle fracture has been observed.

a) According to the standards a crack has to be applied before testing. How do you apply this crack to the sample and what is the length of it *(2 Points)*?

b) **Appendix 2** shows a force-crack tip opening displacement diagram. Determine the breaking force using the given diagram *(2 Points)*?



Appendix 1: technical sketch showing a CT 0.5 specimen



Appendix 2: force-crack tip opening displacement diagram

B = 12,5 mm W = 25 mm

c) Use the following equations to calculate the K_{Ic}-value, assuming linear elastic fracture mechanics conditions. Consider your results from task a). In case your result from part a) is a range of valid values, you can take one value *(6 Points)*.

$$K_I = \frac{F}{BW^{1/2}} f(\lambda)$$

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

$$f(\lambda) = \frac{(2+\lambda)(0,886 + 4,64\lambda - 13,32\lambda^2 + 14,72\lambda^3 - 5,6\lambda^4)}{(1-\lambda)^{3/2}}$$

B = 12,5 mm W = 25 mm

Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
E-Mail: bleck@iehk.rwth-aachen.de Fax: +49 241 8092224

Task 10 fatigue testing 8 Points

The fatigue behaviour of metallic materials can be described using "Wöhler"-lines.

a) Sketch the "Wöhler"-line for a bcc steel and an Aluminium alloy in one diagram. Label the axes and indicate the characteristic areas (*6 Points*).

b) What effect does a temperature increase have on the "Wöhler"-line (*2 Points*)?

Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
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Task 11 high temperature behaviour 7 Points

While designing creep-resistant steels, it is important to consider some basic material factors.

a) Discuss the role of the crystal structure on the creep resistance of high temperature steels. Which crystal structure has the highest creep resistance? Give a short explanation *(2 Points).*

b) Explain why martensitic or bainitic steels have a higher creep resistance compared to ferritic steels *(1 Point)*?

c) Why are single crystals used for high temperature applications instead of polycrystalline metalls *(1 Point)?*

d) How is solid the solution strengthening different at high temperatures compared to room temperature *(1 Point)*?

e) Which kind of particles, i) carbonitrides or ii) intermetallic phases should be used for particle strengthening at high temperatures? Give a short explanation *(2 Points).*

Task 12 sheet testing 8 Points

a) Assign the given materials i)–iv) to the shown car body parts A (roof), B (front body structure) and C (B-pillar) (**Appendix I**). Give a short explanation for your choice! (for each part there can be several kinds of material) *(4 Points)*.

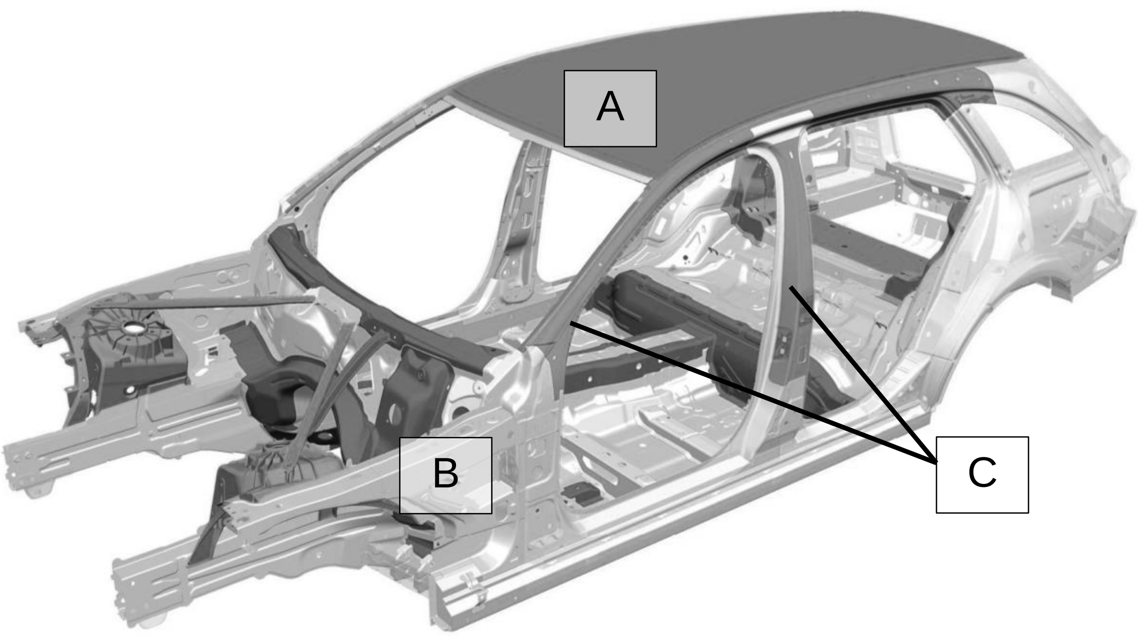
i) Mild Steel, UTS ≈ 200 MPa

ii) UHSS, UTS > 800 MPa

iii) Aluminium

iv) HSS, UTS > 400 MPa

Appendix 1:

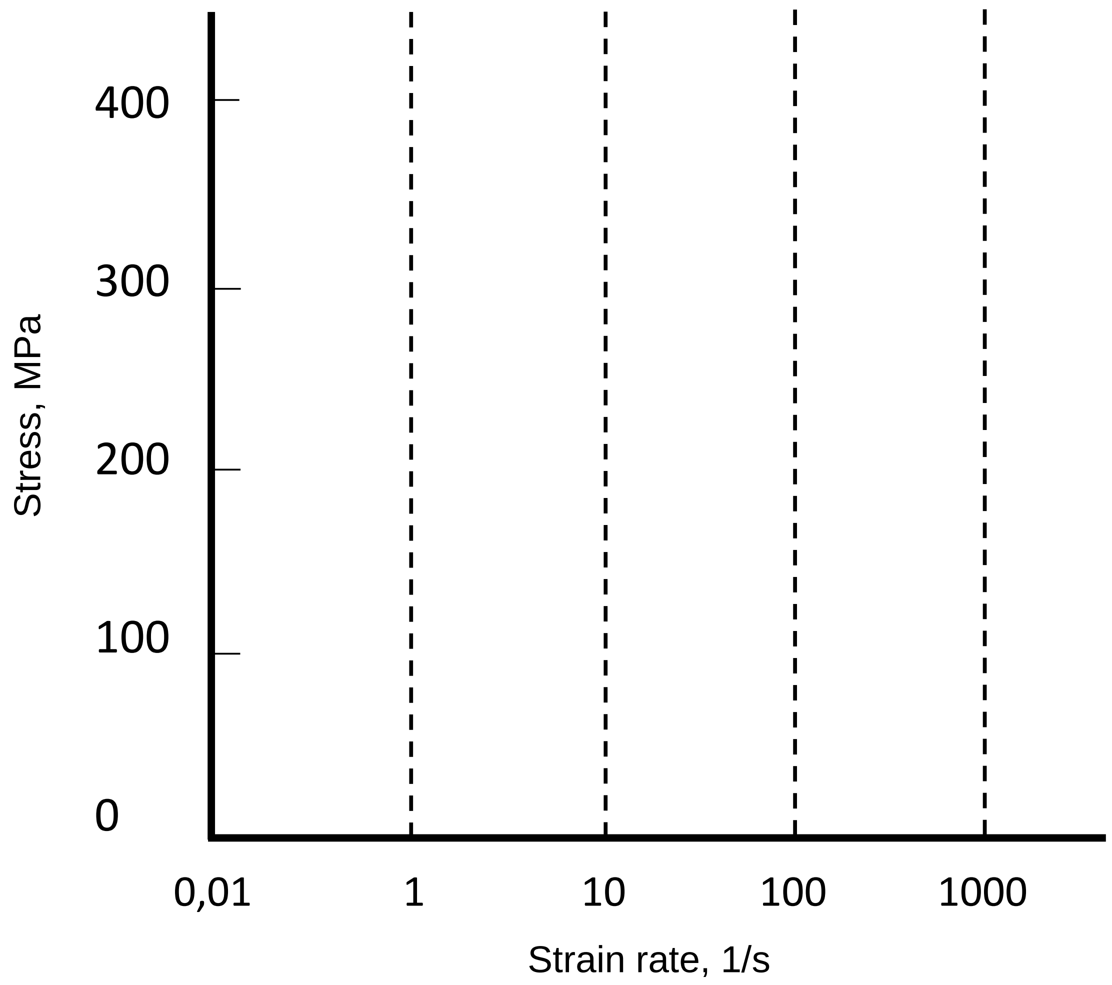


Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
E-Mail: bleck@iehk.rwth-aachen.de Fax: +49 241 8092224

b) Dynamic tensile tests at high strain rates $\dot{\varepsilon} > 1$ 1/s are used to characterize materials used for crash relevant automotive parts.

Sketch the strain rate dependency of the i) yield strength and ii) ultimate tensile strength of an automotive body steel grate (ZStE180BH) in **Appendix 2** *(2 Points).*

Appendix 2:



Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
E-Mail: bleck@iehk.rwth-aachen.de Fax: +49 241 8092224

c) Almost 90% of the deformation energy is converted into heat during the deformation of metals. During testing this heat is released to the surrounding. What is the influence of this so-called dissipation energy during dynamic tensile tests using high strain rates? How do you call this effect (1 Point)?

d) Which value describes the strain rate sensitivity? What is the result of a i) positive or ii) negative strain rate sensitivity (1 Point)?

Head of Department: Univ. Prof. Dr.-Ing. W. Bleck Fon: +49 241 8095782
E-Mail: bleck@iehk.rwth-aachen.de Fax: +49 241 8092224

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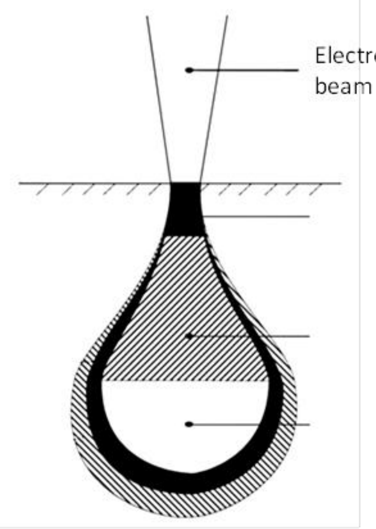
Task 13 electron microscopy 8 Points

Appendix 1 shows a generalized illustration of an interaction volume for electron-specimen interactions.

a) Correlate the marked areas within Appendix 1 with the different types of radiation:

- backscattered electrons
- secondary electrons
- characteristic x-rays. (1 point)

Appendix 1



b) Explain the formation of each radiation mentioned in task a) (3 Points).

c) Different information can be got out of the different radiations. Which type of radiation can be used for the following tasks (4 Points):

- Analysis of chemical composition
- Investigation of fracture surface
- Analysis of crystallographic orientation of separate grains
- Identification of a microstructure within a deep etched specimen.

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