hystories
Hydrogen Storage in European Subsurface

# Full steel characterization

Dissemination level: PU - Public

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# 1. Introduction

In the course of work package WP4 the Hystories project, a material characterization of the steels selected at en earlier stage and reported in D4.2 (List of the steel grades to be investigated) was carried out by the Chair of General and Analytical Chemistry, Montanuniversitaet Leoben.

The following materials (steels) have been handed over:

Carbon steels:
- K55,
- L80,
- Quenched L80,
- P110,
- 20MnV5.

Corrosion Resistant Alloys:
- Alloy 625,
- Duplex 2205,
- 316L.

Chemical analysis, mechanical properties and microstructure were characterised for all materials.

Further investigations should be done (as soon as they are delivered):
- Tensile tests in air at room temperature for the 13%Cr steel,
- tensile tests in glycerine at 120°C and in air at room temperature for the welded K55,
- and for the welded K55 and 13%Cr steel characterization of the microstructure including the average grain diameter (and, if applicable, the average ferrit or austenite content).

# 2.Investigations

The chemical composition was determined by optical emission spectroscopy. The composition of all delivered carbon steels and of all Corrosion resistant alloys (CRAs) is shown in Table 1:

Table 1: Chemical composition of materials to be investigated

| | Sample | C | Si | Mn | P | S | Cu |
|---|---|---|---|---|---|---|---|
| Carbon steels | K55 | 0.37 | 0.21 | 1.19 | 0.014 | 0.006 | 0.11 |
| | L80 | 0.24 | 0.20 | 1.00 | 0.014 | 0.0010 | 0.03 |
| | quenched L80 | 0.25 | 0.19 | 1.01 | 0.017 | 0.0012 | 0.02 |
| | P110 | 0.27 | 0.24 | 1.05 | 0.010 | 0.004 | 0.21 |
| | 20MnV5 | 0.18 | 0.20 | 1.12 | 0.016 | 0.004 | 0.16 |
| CRAs | 2205 | 0.019 | 0.48 | 1.73 | 0.025 | 0.0010 | 0.13 |
| | Alloy 625 | 0.019 | 0.10 | 0.21 | 0.007 | 0.0006 | 0.01 |
| | 316L | 0.012 | 0.35 | 1.61 | 0.025 | 0.0019 | 0.23 |

| | Sample | Cr [%] | Ni [%] | Mo [%] | W [%] | V [%] | Nb [%] |
|---|---|---|---|---|---|---|---|
| Carbon steels | K55 | 0.18 | 0.09 | 0.09 | 0.01 | - | - |
| | L80 | 0.31 | 0.05 | 0.02 | <0.01 | - | - |
| | quenched L80 | 0.31 | 0.04 | 0.02 | <0.01 | - | - |
| | P110 | 0.28 | 0.07 | 0.02 | <0.01 | - | - |
| | 20MnV5 | 0.08 | 0.07 | 0.02 | <0.01 | 0.06 | - |
| CRAs | 2205 | 22.38 | 5.09 | 3.40 | 0.04 | 0.03 | - |
| | Alloy 625 | 19.65 | 57.79 | 7.56 | 0.02 | 0.03 | 3.10 |
| | 316L | 16.92 | 11.27 | 2.11 | 0.03 | 0.11 | - |

| | Sample | Ti [%] | Co [%] | B [%] | Al [%] | Sn [%] | $N_2$ [%] |
|---|---|---|---|---|---|---|---|
| Carbon steels | K55 | - | 0.03 | 0.0002 | 0.020 | 0.009 | 0.0092 |
| | L80 | - | 0.01 | 0.0019 | 0.039 | 0.004 | 0.0042 |
| | quenched L80 | - | 0.01 | 0.0013 | 0.041 | 0.012 | 0.0040 |
| | P110 | - | 0.01 | 0.0008 | 0.028 | 0.011 | 0.0083 |
| | 20MnV5 | - | 0.01 | 0.0001 | 0.024 | 0.013 | 0.0069 |
| CRAs | 2205 | - | 0.07 | 0.0017 | 0.009 | 0.006 | 0.1650 |
| | Alloy 625 | 0.175 | 0.01 | 0.0008 | 0.080 | 0.003 | 0.0110 |
| | 316L | - | 0.13 | 0.0007 | 0.005 | 0.007 | 0.0710 |

The chemical composition of the examined materials corresponds to the specification, except for the nickel-based Alloy 625. There the content of C, Cr, Ni, Mo and Nb is slightly too low, which might be caused due to the weld cladding process (oxidation of these element).

The mechanical properties of the materials were determined by means of a tensile test in a tensile testing machine from ZwickRoell, model "Beta 50". Every material was tested twice. The tensile tests for the K55 and L80 were done at room temperature in air and in glycerine at 120°C. All other materials were tested at room temperature in air. Table 2 documents the results obtained from the stress-strain diagrams of all conditions.

Table 2: Summarization of the tensile test results of all delivered steels

| Sample | Temperature [°C] | Environment | Yield Strength [MPa] | Ultimate Tensile Strength [MPa] | Fracture Elongation [%] | Reduction of Area [%] |
|---|---|---|---|---|---|---|
| K55 | RT | in air | 407 ± 2 | 682 ± 8 | 15.4 ± 0.2 | 54.2 ± 0.8 |
| K55 | 120 | in glycerine | 380 ± 5 | 673 ± 8 | 10.75 ± 0.3 | 41.3 ± 3.3 |
| L80 | RT | in air | 549 ± 11 | 636 ± 1 | 18.7 ± 0.3 | 63.5 ± 1.5 |
| L80 | 120 | in glycerine | 494 ± 4 | 607 ± 0 | 14.5 ± 0.0 | 48.1 ± 1.1 |
| quenched L80 | RT | in air | 1225 ± 15 | 1606 ± 31 | 8.3 ± 0.3 | 51.2 ± 1.4 |
| P110 | RT | in air | 894 ± 6 | 958 ± 10 | 11.8 ± 0.1 | 60.5 ± 0.2 |
| 20MnV5 | RT | in air | 361 ± 16 | 517 ± 6 | 21.3 ± 3.3 | 61.7 ± 0.2 |
| Alloy 625 | RT | in air | tbd | | | |
| Duplex 2205 | RT | in air | 517 ± 27 | 654 ± 47 | 23.2 ± 0.1 | 68.9 ± 0.7 |
| 316L | RT | in air | 202 ± 7 | 469 ± 5 | 53.1 ± 1.4 | 79.9 ± 0.6 |

tbd….to be done

The steel with the highest strength (1606 ± 30.5 MPa) is the quenched L80 steel grade. The material with the lowest strength (517 ± 6.4) is a carbon steel, 20MnV5.

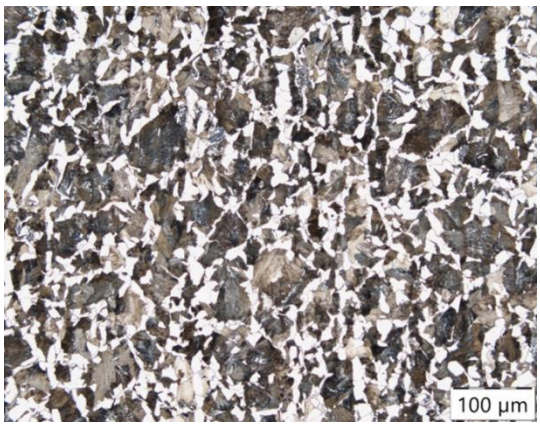
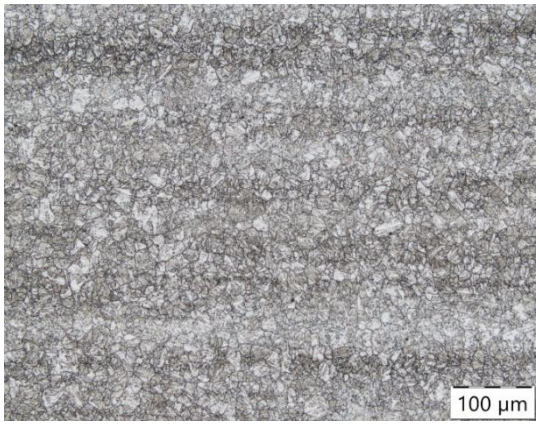
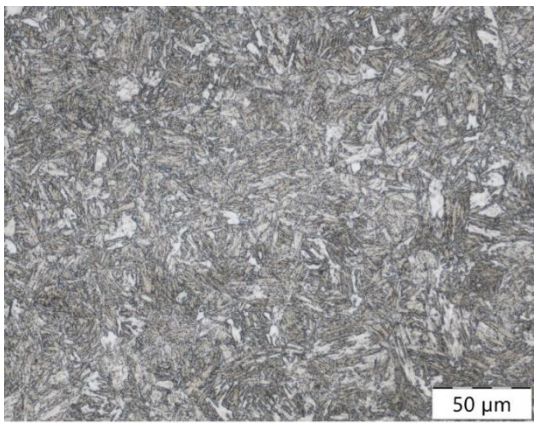
Metallographic sections were made of the materials to investigate their microstructure. The microstructure was examined in an Olympus optical microscope, model AX70.

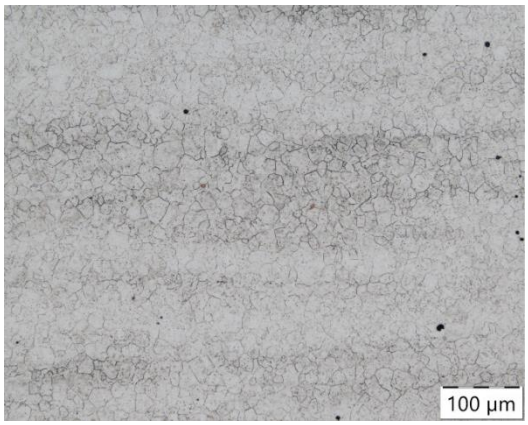
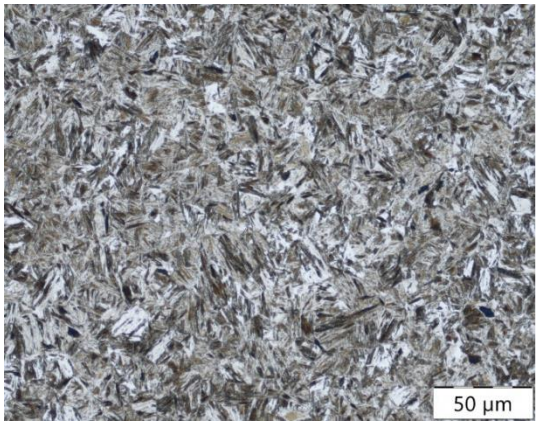
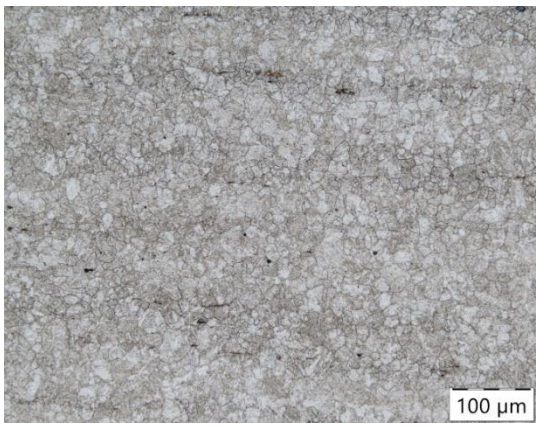
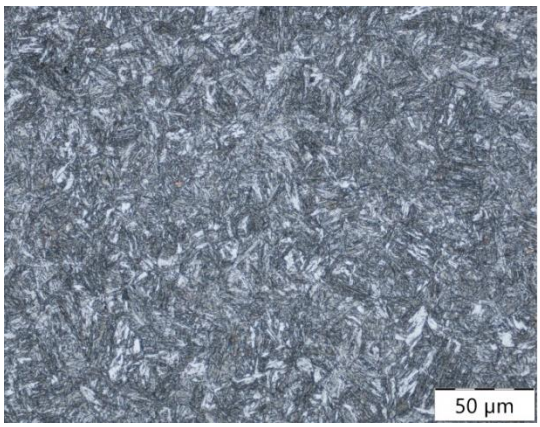
All martensitic microstructures were etched to the grain boundaries of the previous austenite grains with Bechet-Beaujard. The grain size measurement was carried out according to a reference series of comparison in accordance with EN ISO 643. Carbon steels were etched using Nital. The 316L stainless steel and the 2205 duplex steel were etched with a Beraha colour etching agent. The nickel base alloy (Alloy 625) was etched electrochemically (Märkisches Werk, consists of 850ml H2O, 50ml HF and 100ml glycerine) at 4 V and 40 seconds.

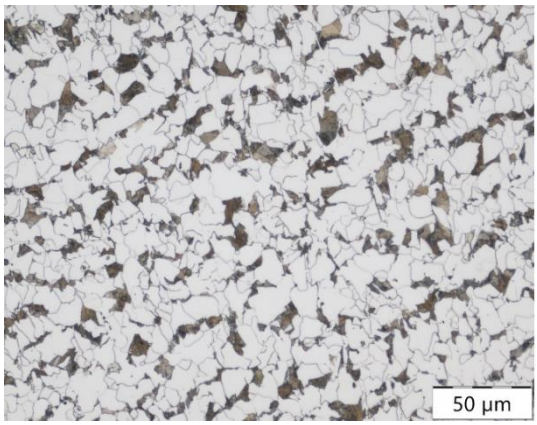
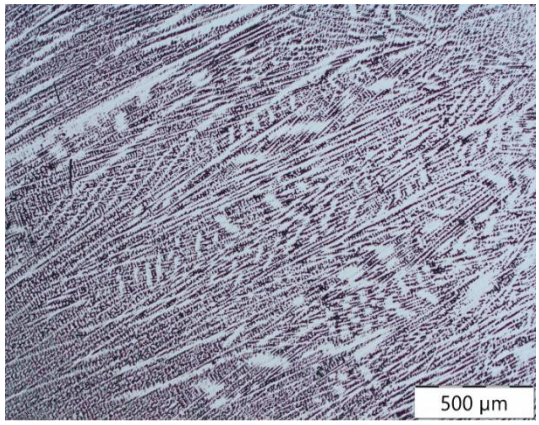
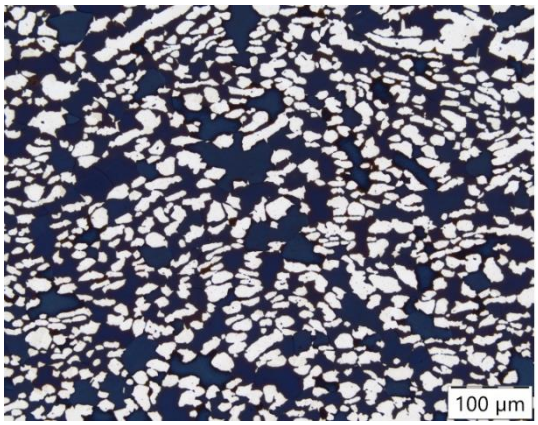
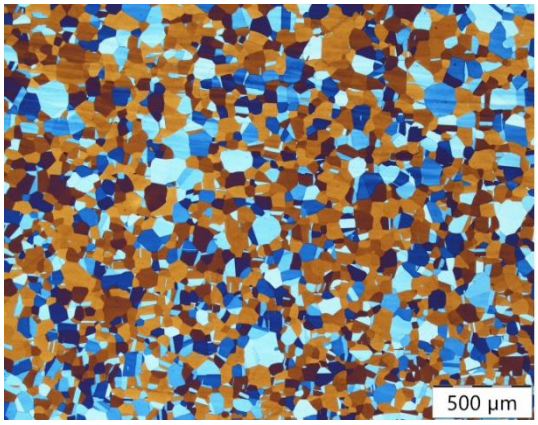
Table 3 shows the microstructure, grain diameter and the etching method of all delivered materials. K55 steel grade consists of ferrite and pearlite with an average ferrite content of 26.1 ± 2.4 % and an average grain diameter of 30 µm. The analysis of the microstructure of the steel grade L80 shows a tempered martensite structure with an average grain diameter of 20 µm. The microstructure of quenched L80 consists of martensite and has an average grain diameter of 15.6 µm. The microstructure of a P110 steel grade, which consists of tempered martensite, has an average grain diameter of 15.6 µm. The 20MnV5 carbon steel shows a

ferrite-pearlite microstructure, with an average ferrite content of 75.8 ± 2.1 % and an average diameter of 11 µm. The microstructure of welded Alloy 625 is dendritic. The microstructure of a Duplex steel 2205 consists of a ferrite and austenite, with an average austenite content of 39.5 ± 3.1 %. The average grain diameter of the Duplex stainless steel is 20 µm. The 316L stainless steel has an average grain diameter of 88.4 µm.

Table 3: Microstructure of the investigated materials

| material | microstructure | grain size [µm] | etchant |
|---|---|---|---|
| K55 |  | 30 | Nital |
| L80 |  | 20 | Bechet-Beaujard |
| L80 |  | | Nital |

| | | | |
|---|---|---|---|
| quenched L80 |  | 15.6 | Bechet-Beaujard |
| quenched L80 |  | | Nital |
| P110 |  | 15.6 | Bechet-Beaujard |
| P110 |  | | Nital |

| | | | |
|---|---|---|---|
| 20MnV5-1 |  | 11 | Nital |
| Alloy 625 |  | | electrolytically etched at 4 V and 40 sec. |
| Duplex 2205 |  | 20 | colour etching with Beraha |
| 316L |  | 88.4 | colour etching with Beraha |

All materials correspond to the current state of technology, regarding purity, grain size, composition, mechanical properties and microstructure. The chemical composition of the examined materials corresponds to their specification, except minor deviations for the nickel-based Alloy 625. The steel with the highest strength is the quenched L80 steel grade. The material with the lowest strength is carbon steel, 20MnV5. There is a fine microstructure for all investigated materials (grain size < 50 µm), only the austenite shows the usual coarser grain size.

# Hystories project consortium

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