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Phase Transformation and Deformation Behavior of Steels with Different Content of Metastable Austenite

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In this investigation three steels HCT 780T, AISI 347 and HSD® 600 with different content of metastable austenite and different austenite stability were monotonically loaded at ambient temperature. Using x-ray diffraction and scanning electron microscopy changes in the microstructure were characterized in detail. Hence, the most important mechanisms, which occur by deformation were determined.

Key words: metastable austenite, TRIP, TWIP, XRD, EBSD, ECCI.

1. General

Metastable austenitic microstructures at ambient temperature can be achieved in steels by alloying chemical elements like Cr, Ni, Mn, Si and Al [1, 2]. Dependent on the amount of these elements and special heat treatments, advanced steels with a low content of retained metastable austenite (<15 vol.-%) – so-called low alloyed TRIP steels – or fully austenitic steels – so-called high alloyed TRansformation Induced Plasticity/TWinning Induced Plasticity (TRIP/TWIP) steels – can be produced. Some of the low alloyed TRIP steels were included in the new German/European standard DIN-EN 10346. The initial microstructure of these steels after heat treatment is mainly a ferritic-bainitic matrix with dispersed retained metastable austenite islands. The fully austenitic TRIP/TWIP steels are generally based on two alloying concepts: 1st: Cr-Ni-concept for corrosion resistant stainless steels (18% Cr/10% Ni) and 2nd: Mn-Si-Al-concept for new advanced austenitic steels, in which a large variance in chemical composition exists and in some cases an addition of Cr and Ni is used.

Depending on the chemical composition and consequently varying stacking fault energy in the metastable fully austenitic steels, the TWIP-effect occurs along or instead of the TRIP-effect [3].

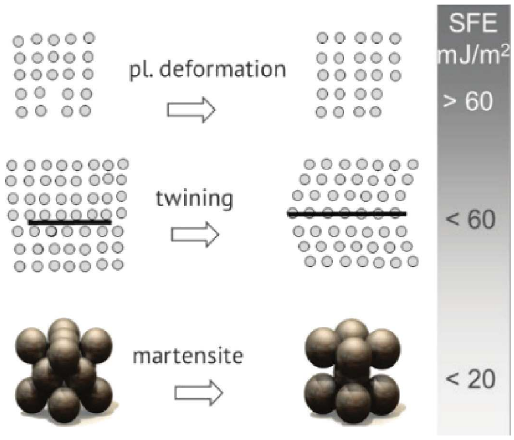

Fig. 1. Nature of microstructural changes during deformation in dependency of stacking fault energy.

2. Investigated materials and methods

In this contribution mechanical properties as well as the microstructure of three types of metastable austenitic steels: (1) low alloyed TRIP, (2) Cr-Ni stainless steel and (3) Mn-Al-Si (TRIP/TWIP) steel are presented and discussed. The chemical composition is given in Table 1. The low alloyed TRIP steel HCT 780T was investigated as-received. Two another steels were investigated after special heat treatment. The metastable austenitic steel AISI 347 was solution annealed at 1050°C for 35 min and quenched in Ar_2. The HSD® 600 steel was solution annealed at 1050°C for 180 min and quenched in H_2O.

Table 1. Chemical composition of investigated steels in wt.-%.

Type	Name	C	Cr	Ni	Mn	Si	Al
(1) Low alloyed TRIP	HCT 780T	0.25	–		–	2.0 (Si+Al)	
(2) Cr-Ni (stainless steel)	AISI 347	0.02	17.3	9.3	1.6	0.6	–
(3) Mn-Al-Si (TRIP/TWIP)	HSD® 600	0.24	–	–	14.2	2.8	1.4

For mechanical tensile load a tensile stage with max. load of 5 kN, company Kammrath & Weiss was used. All tests were performed at flat specimens with a measuring length of 10 mm at ambient temperature. The microstructure investigations were performed using scanning electron microscope (SEM), company FEI, type Quanta 600 using conventional secondary electron images, the electron backscatter diffraction technique (EBSD) and the electron channelling contrast imaging (ECCI) technique. For phase analyzes, the x-ray diffraction method operating with $Cu_{\alpha 1}$-radiation at 40 kV and 40 mA and a spot size of

0.4×12 mm was used. The quantitative phase analysis of the x-ray diffraction patterns is carried out by the Rietveld-Method.

3. Results

3.1. Tensile test

Figure 2 shows deformation curves obtained from tensile tests of the three investigated steels. Due to very high strain and limited measure strain of 10% of the used extensometer, the strain was calculated on the basis of the grips displacement taking into account the gauge length of the specimen. Additionally, the elongation is inserted on the abscissa.

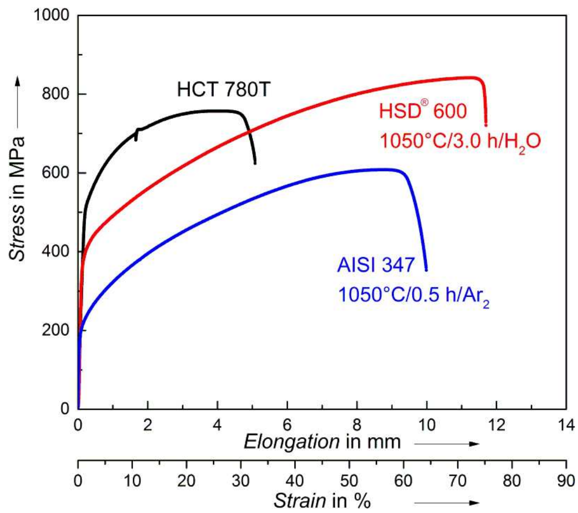

Fig. 2. Stress-elongation curves of investigated steels.

The highest tensile stress with simultaneously existing of the highest elongation (strain) shows the HSD® 600 steel in solution annealing state (1050°C/ 3.0 h/H_2O). Without heat treatment this steel can achieve tensile stresses of 1050 MPa and fracture elongations of 50% [4]. Obviously due to the heat treatment a further increase of deformability at the expense of reduction of strength is possible for this material. The HCT 780T steel achieved a good strength and a relative high deformation of 4.3 mm. AISI 347 shows the smallest strength of all investigated materials and a high deformation at specimen failure of 10 mm. Hence, typical deformation behavior for conventional steels cannot be seen only simultaneously increase of both values: stress and strain. The deformation induced microstructural changes, which significantly influence the deformation behavior will be analysed below.

3.2. Phase transformation in low alloyed TRIP-steel

The microstructure of low alloyed TRIP-steel as-received is shown in Fig. 3a and consists of a hard bainite phase embedded in ductile ferritic matrix with the same value of retained austenite. Due to fine bainitic microstructure the detection of retained austenite by scanning electron microscope is difficult. Therefore, x-ray diffractions of initial state and after specimen failure were preformed (Fig. 3b). Peaks of retained austenite are clearly seen in the diffractogram before tensile test. As a results of plastic deformation the phase transformation from fcc-austenite to bcc-martensite occurred. Using Rietveld-Method the amount of retained austenite before tensile loading could be determined as 7 vol.-% and after tensile test it was reduced to 0 vol.-%. The phase transformation made it possible to achieve high elongation and very good strength at the same time. This phenomenon is based on the TRansformation Induced Plasticity (TRIP) effect which takes place in the retained austenite.

3.3. Phase transformation in high alloyed Cr-Ni austenitic steel

The high alloyed Cr-Ni steel has a fully austenitic microstructure before tensile test. This microstructure is metastable and transforms due to plastic deformation under M_d-temperature (about ambient temperature) to stable martensite phase. This phase transformation was investigated by EBSD.

Figure 4 shows a grain orientation and phase distribution at different strains. Pronounced areas of bcc-martensite is arranged in horizontal aligned stripes, which correspond to the loading axis. The formation of bcc-martensite in Cr-Ni-steels leads to high deformation without significant increase of stress, which is typical for the high alloyed TRIP-steel, see [1, 2]. This behavior can be explained by the small content (0.02 wt.-%) of carbon in Cr-Ni-steel. In this case the bcc-martensite has a small hardness of 380 HV0.01 [5], because the crystallographic structure is not distorted by carbon atoms. For this reason, no significant increase of strength due to the development of martensite is observed. However, the bcc-martensite formation leads to grain refinement (Fig. 4 above), which locally reinforces the microstructure and leads to high global deformations (Fig. 2).

3.4. Deformation behavior of HSD® 600 steel

The microstructure of HSD® 600 in solution annealing state (1050°C/3.0 h/ H_2O) is shown in Fig. 5a. Due to high solution time grain growth occurs and leads to the mean grain size of about 120 μm without consideration of the solution annealing twins.

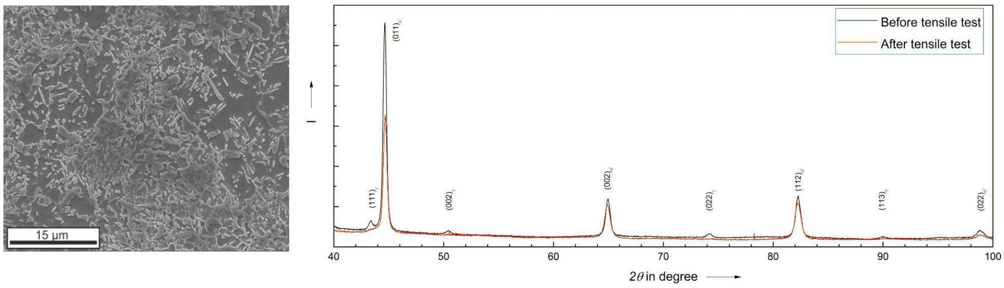

FIG. 3. SEM-micrograph of initial microstructure and diffractograms before and after tensile test of HCT 780T.

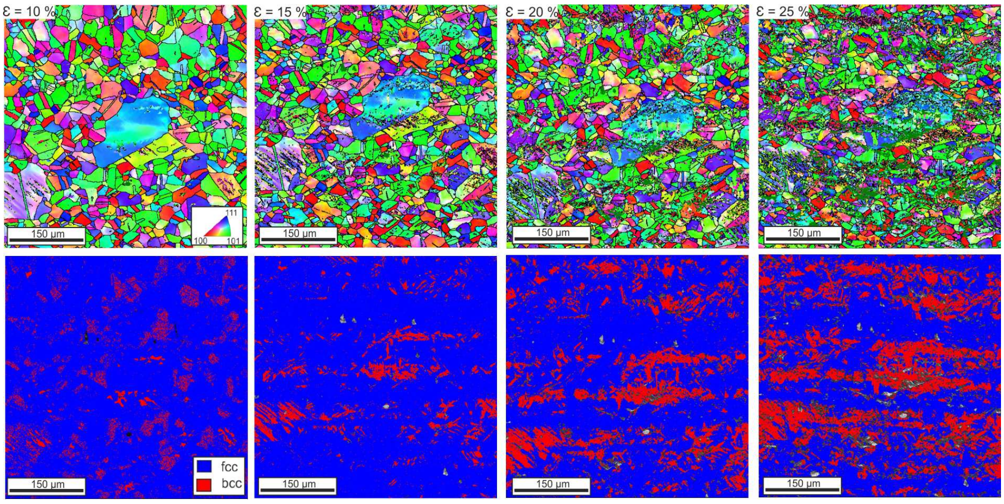

FIG. 4. EBSD mappings with grain orientation (above) and phase distribution (below) from AISI 347 at different tensile strains.

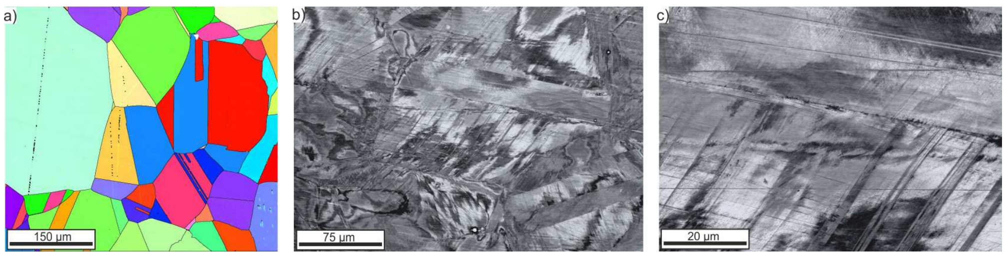

FIG. 5. SEM-micrographs, (a) EBSD mappings with grain orientation of microstructure before tensile test, (b) and (c) ECCI after 20% elongation of HSD® 600.

For investigations of microstructural changes as a results of tensile elongation a specimen was strained up to 20% and finally investigated using ECCI-technique. This technique provides the possibility to investigate the lattice defects (dislocations, twins, stacking faults) as well as the defect arrangements (walls, cells) in the bulk material [6]. In Fig. 5b two grains with solution annealing twins can be clearly seen, comparable to initial microstructure showed in the EBSD-micrograph (Fig. 5a). Moreover, further thin deformation twins were detected (see detail form Fig. 5b in Fig. 5c). These deformation twins fundamentally effect the deformation behavior and lead to a very high deformation of HSD® 600 steel. In literature, this mechanism is called a dynamic Hall-Petch-relationship because of the grain refinement due to the twinning of the microstructure under load.

4. Conclusion

In the present study, the influence of different content of metastable austenite and its stability on deformation behavior during monotonic loading was presented. The three steels HCT 780T, AISI 347 and HSD® 600 were tensile loaded. The HCT 780T steel has 7 vol.-% of metastable austenite before tensile test. The two other steels AISI 347 and HSD® 600 have a fully austenitic microstructure before tensile test. During monotonic loading the metastable fcc-austenite transforms in HCT 780T and AISI 347 to bcc-martensite. This phenomenon is called TRansformation Induced Plasticity (TRIP) effect. In contrast to this, in HSD® 600 steel no phase transformation due to monotonic loading occurred. In this material a significant development of deformation induced twins was detected by using ECCI-technique, which is called TWinning Induced Plasticity effect. Hence, under consideration of the initial microstructure and the different content of metastable austenite as well as using TRIP- and/or TWIP-effects, various mechanical properties of these kind of steels can be adjusted.

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