



Microstructural investigation of the fatigue behavior and phase transformation in metastable austenitic steels at ambient and lower temperatures



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ABSTRACT

Microstructural investigations of the fatigue behavior and phase transformation in the metastable austenitic steels AISI 304 and 348 were performed. The specimens were cyclically loaded with a constant total-strain-amplitude in the temperature range $-60\text{ }^{\circ}\text{C}$ to $25\text{ }^{\circ}\text{C}$. By means of stress-strain hysteresis and magnetic measurements, the fatigue behavior and phase transformation were characterized. Microstructural changes were evaluated by transmission electron microscopy and by scanning electron microscopy by means of electron backscatter diffraction technique at defined fatigue states. The steels show differences in austenite stability, which lead to significant changes in the deformation induced martensite formation and the fatigue behavior. Dependent on the type of steel and the testing temperature similar α' -martensite fractions but different strengths developed.

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1. Introduction

Various austenitic steels are in a metastable state up to ambient temperature and can transform into martensite due to plastic deformation [1–3]. The transformation goes along with changes in the lattice structure in which three transformation paths are known [4]. The fcc γ -austenite may transform into hcp ε -martensite or bcc α' -martensite directly, but also the consecutive transformation γ - ε - α' may occur. Phase transformation from paramagnetic austenite into ferromagnetic α' -martensite leads to a significant change in the fatigue behavior due to the enhanced strength of the martensitic phase and can be detected by non-destructive magnetic measuring techniques [5–7]. The austenite stability, viz. susceptibility to formation of deformation induced martensite, depends on the chemical composition, the temperature and the degree of plastic deformation. The influence of the chemical composition on the austenite stability is usually characterized with the martensite start temperature M_s for thermally induced martensite formation and the so-called M_{d30} -temperature for deformation induced martensite formation. By definition M_{d30} represents the temperature at which 50% α' -martensite are formed due to a plastic deformation of 30%. Several empirical equations have been developed over the years to calculate these temperatures [8–15]. Mostly the equations according to Eichelmann and Angel are used to estimate the M_s - and M_{d30} -temperature, respec-

tively. However, these widely known equations do not include the influence of the content of niobium on the austenite stability, which is added in AISI 348 to improve the resistance against intergranular corrosion. Moreover, additional alloying with niobium leads to the formation of niobium-carbides, which reduces the carbon content in solution and therefore reduces the austenite stability. In case of niobium alloyed austenitic steels, this phenomenon is taken into account when calculating the M_{d30} -temperatures according to Nohara et al. [14]. Another influence on the transformation behavior from austenite into either ε - and/or α' -martensite are stacking faults and the stacking fault energy in the γ -austenite [16–18]. The deformation induced martensite formation has been intensively investigated [8] and modeled [19] for monotonic loading of austenitic steels at ambient (AT) and lower temperatures (LTs). Furthermore the deformation induced martensite formation under cyclic loading at AT [1–3] and LT [20–22] is known in literature, but only few models exist, which describe the deformation induced martensite formation under cyclic loading at AT [23]. No model of deformation induced martensite formation under cyclic loading exists for LT and only very few data exists about their influence on the fatigue behavior of austenitic steels at LT.

2. Materials and experimental setup

2.1. Chemical composition

The investigated materials are the metastable austenitic steels AISI 304 (X5CrNi1810, 1.4301) and AISI 348 (X10CrNiNb189,

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Table 1
Chemical composition (weight-%).

	C	Cr	Ni	Ti	Nb	Mn	Mo	N
AISI 304	0.040	18.29	8.19	0.01	0.02	1.40	0.18	0.078
AISI 348	0.021	17.44	9.34	0.01	0.36	1.47	0.34	0.009
	Cu	Si	P	S	V	W	Co	Fe
AISI 304	0.19	0.36	0.040	0.012	0.03	0.02	0.10	Bal.
AISI 348	0.09	0.54	0.023	0.009	0.11	0.01	0.05	Bal.

1.4546). Their chemical composition, measured by spectroscopic analysis, is given in Table 1. To obtain a homogeneous microstructure, solution annealing at $T = 1050$ °C for 35 min with subsequent quenching in helium atmosphere was performed. Afterwards average grain sizes of $42 \mu\text{m}$ (ASTM-No. 6.2) for AISI 304 and $16 \mu\text{m}$ (ASTM-No. 9.3) for AISI 348 were measured in longitudinal sections treated with V2A etchant. Fig. 1 shows the corresponding SEM images of the two materials to illustrate the different grain sizes.

2.2. Parameters of the austenite stability

As mentioned the austenite stability of metastable austenitic steels is mainly influenced by the chemical composition. Multiple empirical formulae have been developed to estimate the austenite stability by the specific parameters of the M_S - and M_{d30} -temperature. But it is essential to say that the resulting temperatures are no absolute values. Their use is of comparative kind, e.g. to compare steels from different heats or different types of austenitic steels in terms of their susceptibility to the austenite–martensite transformation. Calculating the values of the M_S - and M_{d30} -temperature, respectively, according to the following equations, provides Table 2.

$$M_{S,Eichelmann} = 1350 - 1665(C + N) - 28Si - 33Mn - 42Cr - 61Ni \quad [9]$$

$$M_{S,Monkman} = 1182 - 1456(C + N) - 37Cr - 57Ni \quad [10]$$

$$M_{S,Pickering} = 502 - 810C - 1230N - 13Mn - 30Ni - 12Cr - 54Cu - 46Mo \quad [11]$$

$$M_{d30,Angel} = 413 - 462(C + N) - 9.2Si - 8.1Mn - 13.7Cr - 9.5Ni - 18.5Mo \quad [8]$$

$$M_{d30,Gladman} = 497 - 462(C + N) - 9.2Si - 8.1Mn - 13.7Cr - 20Ni - 18.5Mo \quad [12]$$

$$M_{d30,Sjoberg} = 608 - 515C - 821N - 7.8Si - 12Mn - 34Ni - 13Cr - 6.5Mo \quad [13]$$

$$M_{d30,Nohara} = 551 - 462(C + N) - 9.2Si - 8.1Mn - 13.7Cr - 29(Ni + Cu) - 18.5Mo - 68Nb \quad [14]$$

$$M_{d30,Nohara,GS} = M_{d30,Nohara} - 1.42(v - 8), v = \text{ASTM No.} \quad [15]$$

It is obvious that in most cases the composition of the steel AISI 348 compared to AISI 304 results in higher M_S - and M_{d30} -temperatures which means that its austenite stability is lower, or, in other words, the deformation induced martensite formation is possible up to higher temperatures. The temperatures calculated according to Nohara, which predict higher austenite stability for the steel AISI 348, are not suitable for a comparison between the two steels, because the formula takes the content of niobium into account of which the steel AISI 304 is not alloyed with. Furthermore the grain size of the material may have an influence on the austenite stability, which is regarded in the formula according to Nohara, GS. From the formula and the calculated values it can be seen, that smaller (larger) grain size suppresses (increases) the deformation induced martensite formation. Nohara assumes the influence transition of the grain size at an ASTM-No. of 8. In literature [24,25] different influences of the grain size on the austenite stability are discussed. Raman et al. found an increase of the martensite content with larger grain size, whereas Shrinivas et al. found the opposite dependency. In general, a separation of the influence of different grain sizes on the austenite stability is difficult, because the grain size also influences other material properties in tensile and cyclic tests, e.g. plastic deformation and strength, fatigue life, dislocation formation and mobility.

2.3. Monotonic properties

Prior to tensile tests, macroscopic Vickers hardness values with 10 kp indentation force were measured for the investigated austenitic steels in the solution-annealed state. The steel AISI 304 showed a higher hardness of 208 HV 10 compared to the steel AISI 348 with 177 HV 10. Tensile tests were performed with constant displacement control mode. Crosshead speed was chosen

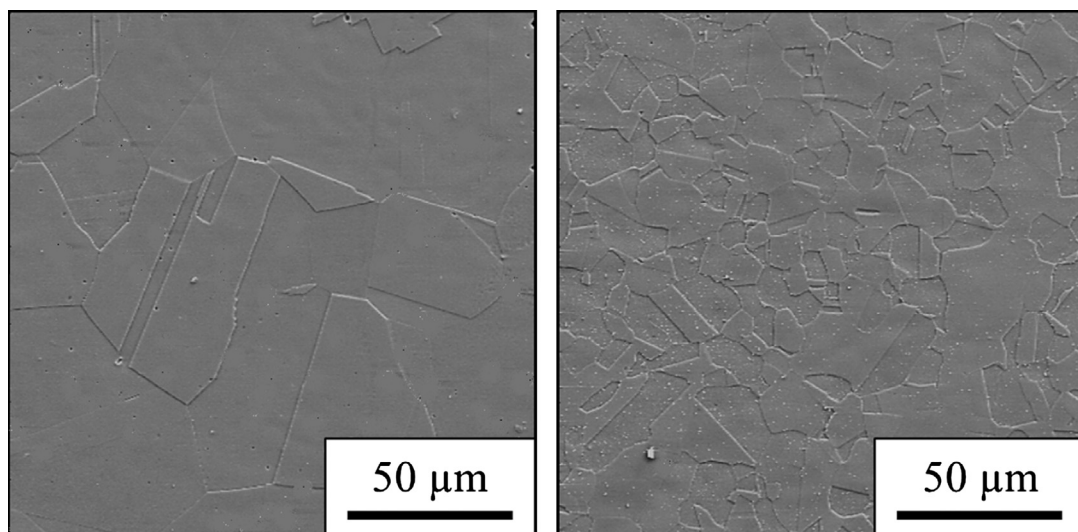


Fig. 1. Initial state SEM images of AISI 304 (left) and AISI 348 (right).

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