Micromagnetic and Mössbauer Spectroscopic Investigation of Strain-Induced Martensite in Austenitic Stainless Steel

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Strain-induced martensite in 18/8 austenitic stainless steel was studied. Magnetic measurements and Mössbauer spectroscopic investigations were performed to characterize the amount of α'-martensite due to room-temperature plastic tensile loading. The effects of cold work and annealing heat treatment were explored using magnetic Barkhausen noise, saturation polarization, coercive force, hardness, and conversion electron Mössbauer spectra measurements. The results of the magnetic measurements were compared to results obtained by Mössbauer spectroscopy. The suggested Barkhausen noise measurement technique proved to be a useful quantitative and nondestructive method for determining the ferromagnetic phase ratio of the studied alloy.

The mechanical behavior of austenitic stainless steels during cold work can be described as follows (Ref 4):

- When austenite is stable and the stacking fault energy is high, glide of perfect dislocations is the principal mechanism of plastic deformation.
- When the stability of the austenite and the stacking fault energy decrease, four new modes of deformation become competitive with the glide of perfect dislocations:

1. Glide of partial dislocations
2. Microtwinning
3. γ → ε transformation
4. γ → α' transformation directly or via the path γ → ε → α'

The gradual transformation of austenite to strain-induced martensite increases the work hardening of these steels. The fine α'-martensite grains appear inside the austenite grains mainly at the intersections of shear bands, making the movement of dislocations more difficult. However, the α'-martensite is not an effective strengthener compared to the classical thermal martensite in iron-carbon systems.

The α'-phase is thermodynamically much more stable than the ε-phase. The ε-phase forms before the α'-phase during cold working of a low-carbon 18/8-type steel. At higher deformations, the amount of the previously formed ε-phase decreases with increasing deformation because the α'-martensite grows at the expense of the ε-phase (Ref 5). The transformations of austenite to ε- and α'-phases are diffusionless or military type.

The reverse transformation of ε-phase occur between 150 and 400 °C, followed by the reversion of α'-phase above 400 °C (Ref 3). Both the ε- and the α'-martensite transform directly into austenite phase.

All austenitic stainless steels are paramagnetic in the annealed, fully austenitic condition. The hcp ε-martensite is paramagnetic in contrast to the bcc α'-martensite, which is strongly ferromagnetic (hard magnetic) and the only magnetic phase in the low-carbon austenitic stainless steels (Ref 6). Therefore, the cold-worked austenitic
stainless steels have detectable magnetic properties that can be eliminated by annealing.

2. Experimental Method

The appearance of \(\alpha'\)-martensite was investigated during cold work, and the disappearance of this phase was studied during the annealing process.

2.1 Material

The chemical composition of the 18/8-type titanium-stabilized austenitic stainless steel used in this investigation was Fe-0.08C-1.8Mn-0.98Si-17.8Cr-8.22Ni-0.32Mo-0.75Ti-0.036P -0.0275 (mass percent). Strip-shaped specimens, 25 mm wide and 180 mm long, were cut from the original 2 mm thick stainless steel plate. The specimens were annealed at 1100 °C for 1 h before water quenching to prevent carbide precipitation. The measured primary grain size of the annealed stainless steel specimens was 28 \(\mu\)m.

2.2 Applied Measuring Methods

The Barkhausen noise was investigated by using a sinusoidal (10 Hz) exciting magnetic field produced by a function generator and a power amplifier. The applied measuring head contained a U-shape magnetizing coil and a pickup coil perpendicular to the surface of the specimen. The signal of the pickup coil was processed by a 0.3 to 38 kHz bandpass filter and amplified with a gain of 100. A KRENZ TRB 4000 (Krenz Electronics, Inc., Chicago, IL) computer-controlled signal-analyzing device was used to process the noise. The applied sampling frequency was 100 kHz. The power spectrum was calculated from the digitized time signal and integrated between the frequency limits of 2 and 38 kHz. The obtained value, which is proportional to the energy of the Barkhausen noise (BN energy) in the investigated frequency range, was used to characterize the microstructural changes. The applied magnetizing field strength corresponds to the irreversible domain wall displacement range on the hysteresis loop. Details of the Barkhausen noise measuring apparatus and the applied measurement method have been described previously (Ref 7, 8).

The saturation polarization \(J_{\text{max}}\) was measured by a ballistic method. The largest applied external magnetic field strength was 8750 A/cm, which was sufficient for reaching the magnetic saturation of the ferromagnetic \(\alpha'\)-phase:

\[
J_{\text{max}} = B_s - \mu_0 H
\]

where \(B_s\) is the saturation induction, \(H\) is the applied external magnetic field, and \(\mu_0\) is the magnetic permeability of the vacuum. In both series of experiments, the Vickers hardness was measured with a load of 98.1 N.

Mössbauer spectroscopy is an accurate and reliable measuring technique for determining the ferromagnetic/paramagnetic ratio of alloys (Ref 9). The conversion electron Mössbauer spectra (CEMS) were recorded by a Ranger (Texas Instruments, Inc., Attleboro, MA) conversion electron detector at room temperature using a spectrometer working with constant acceleration. The SIRIUS (Sirius Systems Technology, Pasadena, TX) program was used for fitting the spectra.

3. Results and Discussion

3.1 First Experimental Series

The as-annealed stainless steel specimens were elongated at room temperature (20 °C) up to about 50% strain and were subjected to a heat treatment at 520 °C for 30 min. The BN energy and the hardness values were measured. In this and in the second series of experiments, a very low elongation rate (1 mm/min) and continuous water cooling were used to ensure a specimen temperature of 20 °C during plastic tensile loading.

\[
J_{\text{max}} = B_s - \mu_0 H
\]

where \(B_s\) is the saturation induction, \(H\) is the applied external magnetic field, and \(\mu_0\) is the magnetic permeability of the vacuum. In both series of experiments, the Vickers hardness was measured with a load of 98.1 N.

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