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Magnetic investigation of the effect of α′-martensite on the properties of austenitic stainless steel

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Abstract

In this paper some phase transformations of the AISI 304 austenitic stainless steel are studied. The appearance of the strain induced α′-martensite phase due to cold rolling and elongation was investigated by different magnetic measurement techniques. It was demonstrated that the type of deformation and the rate of deformation strongly influence the amount of α′-martensite phase. It is supposed that the additional stress due to the specific volume change of γ→α′ transformation can improve the plastic deformation of the neighbouring austenite grains in the highly deformed range which has increasing effect on the amount of α′-martensite phase. The reverse transformation of the α′-phase back to γ-phase due to heat treatment is also studied. It was proved that the magnetic and hardness recovery processes started at different temperatures. The paper demonstrates the application possibility of magnetic measurements in case of the investigated metallurgical problem.

Keywords: Austenitic stainless steel; Strain induced martensite; Phase transformation; Magnetic barkhausen noise; Micromagnetic measurements

1. Introduction

In this paper, the strain-induced phase transformations of austenitic stainless steel, and the role of the α′-martensite phase in the hardening process are studied. The paper demonstrates an application possibility of magnetic Barkhausen measurement in case of the investigated metallurgical problem.

It is known that the plastic deformation of 18% Cr- and 8% Ni-containing austenitic stainless steels during cold working results in three main products: the appearance of ε-phase and α′-phase and increased dislocation densities within the host material.

Two types of phases can form on cooling (thermally) or cold working (mechanically) in austenitic stainless steels. The formation of these phases is a result of a diffusionless phase transformation, which can occur above the M_s-temperature. The ε-phase, which forms close-packed (1 1 1) planes in the austenite, has hexagonal (hcp), and the α′-phase has bcc crystal structure. The kinetics of $\gamma \rightarrow \varepsilon$ and $\gamma \rightarrow \alpha'$ phase transformations was extensively studied by different authors [1,2]. The α′-phase is often called strain-induced martensite because it is produced by a diffusionless phase transformation. The results of X-ray diffraction, magnetic measurements, and transmission electron microscopy led the researchers to believe that the most probable way of the phase transformation is the $\gamma \rightarrow \varepsilon \rightarrow \alpha'$ [3]. It was found that the α′-phase is formed almost exclusively at the intersection of twin faults or shear bands (bands of imperfect micro twins), stacking faults, and ε-phase [4]. Olson et al. [5] have proposed a model for predicting the volume-fraction of strain-induced martensite considering the processes of shear band formation and their intersection to become a martensite embryo.

The lattice parameters of the γ-, ε- and α′-phases are determined by X-ray diffraction techniques, $a_\gamma = 0.3585 \pm 0.0002$ nm, $a_{\alpha'} = 0.2872 \pm 0.0002$ nm [6,7]. Therefore, the $\gamma \rightarrow \alpha'$ phase transformation is accompanied by a volume expansion of 2.83%.

Depending on the temperature the ε- and α′-phases can be metastable. The reverse transformation of ε-phase occurs in the temperature range 150–400 °C. The α′-phase is more

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stable: the $\alpha' \rightarrow \gamma$ reverse transformation takes place at temperatures of 400–800 °C [6].

All austenitic stainless steels are paramagnetic in the annealed, fully austenitic condition. The hcp ε-phase is paramagnetic in contrast to the bcc α′-martensite, which is strongly ferromagnetic, and the only magnetic phase in the austenitic stainless steels. Because of the α′-phase, the cold-worked austenitic stainless steels have detectable magnetic properties that can be eliminated by annealing.

The aim of the present work is to study the strain-induced martensite formation, due to cold working and the reverse-transformation of this phase back to austenite in 18/8 type austenitic stainless steels. Magnetic measurements have been made to characterize the amount of α′-martensite due to room temperature rolling and tensile testing. The effect of cold work and annealing heat treatment was studied on the magnetic Barkhausen noise, relative permeability, and Vickers hardness measurements. The microstructure and the phase ratio of the stainless steel specimens were investigated by optical metallographic technique.

2. Experimental procedure

2.1. Investigated material

In this work, the AISI 304 type austenitic stainless steel was investigated. The chemical composition, according to the standard and the measured composition by energy dispersive X-ray diffraction (EDS) can be seen in Table 1.

In the first and second set of experiments, 20-mm wide stripe shaped specimens were cut from the original 7.37-mm thick stainless steel plate. For the third set of experiment, 1.8-mm thick and 23-mm wide stripe specimen was used. The specimens were annealed at 1100 °C for 1 h, before they were water-quenched to prevent the carbide precipitation, and to eliminate the stain-induced phases from the material. The estimated average grain size of the annealed stainless steel specimens was 30 μm.

2.2. Applied measuring techniques

Among others, for testing the specimens, magnetic Barkhausen noise measurement was used. It is known that the so-called ordered-magnetic materials (ferro-, antiferro-, ferri-magnetic) contain magnetic domains in which the material is fully magnetised. These domains are separated from each other with 10–500 lattice parameter thick domain walls in which the direction of moments change according to the type of the domain wall.

In an external magnetic field, the magnetic microstructure of a material changes. In relatively small external fields, the mechanism of magnetisation in domain wall movement can be reversible and/or irreversible. During this process, the volume of domains, in which their orientation is close to the direction of the external field, will increase at the expense of the neighbouring domains.

This process is followed by the rotation of moments within domains, at first one by one, and later coherently. As a result of the elementary magnetisation processes, the whole volume becomes saturated (single domain structure) when each magnetic moment is aligned in the direction of the external field.

In the irreversible domain wall displacement range, domain wall movements are not continuous. The abrupt movements of domain walls can induce voltage pulses in a coil placed onto the surface or, around the specimen. The sum of the elementary pulses will result in a quasi-stochastic noise, which is called magnetic Barkhausen noise.

In the present work the magnetic Barkhausen noise was investigated by using sinusoidal (10 Hz) exciting magnetic field, produced by a function generator and a power amplifier. The applied measuring head contains a 'U' shaped magnetizing coil and a pick-up coil, which is perpendicular to the surface of the specimen. The signal of the pick-up coil was processed by a 0.3–38 kHz band pass filter and amplified. A National Instruments PCI-6023E type data acquisition card was used for measuring the noise and a special software was developed for processing and storing the time signals of the measured noise. The applied sampling frequency was 200 kHz. The root mean square (RMS) value of the noise was calculated from the digitised time signal. It was used to characterize the microstructural changes and referred as BN RMS in the following part of this paper. The applied magnetizing field strength corresponds to the irreversible domain wall displacement range on the hysteresis loop. The magnetic field strength produced by the excitation was 58 A/cm. It was measured on surface of the poles of the magnetising joke by a Hall-probe based device.

The α′-martensite content of the specimens was measured by a ferrite tester device. The measuring head of this equipment contains an open magnetic circuit, which is taken to the surface of the tested specimen. This measuring device is based on relative permeability measurement. The measured permeability was calibrated to the ferromagnetic phase content of the specimen. For the calibration of this instrument

Table 1
The chemical composition of the investigated stainless steel (figures in wt.%)

	C_{max}	Si	Mn	P_{max}	S_{max}	Cr	Ni	Fe
Standard composition	0.08	1.00 (max.)	2.00	0.045	0.030	18–20	8–10.5	Rest
EDS measured		0.56	1.49			18.57	8.36	