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Martensite Content of Cold-Worked AISI 304L Chromium-Nickel Austenitic Steel

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Abstract

The paper presents the effect of plastic strain occurring at room temperature in annealed samples of AISI 304L austenitic chromium-nickel steel on content of strain-induced α′ martensite in its structure. The strain was introduced by longitudinal rolling of the samples with constant strain rate of about 300 mm/s and relative cold work ranging from 5% to 90% It has been demonstrated that the share of α′ martensite in microstructure of the steel determined by means of Feritscope FMP30 depends on the degree of cold work.

Key words: Austenitic stainless steel, Longitudinal rolling, Martensitic phase

1. Introduction

Chromium-nickel austenitic steel AISI 304L belongs to a large group of steels with matrix in the form of metastable alloy austenite. When the steels are subjected to cold plastic strain, athermal martensitic transition proceeds in austenite grains. Martensite crystals are formed within the period of about 10^{-7} s without thermal activation [1–3]. Martensitic phase can form also in the surface layer through dynamical interaction of the sand jets with the surface layers of these steels [4].

Martensite coming into existence in austenitic steels as a result of external stresses and strain (stress-induced martensite and strain-induced martensite) is characterized with lens-shaped lamellae with surfaces irregular to a variable degree. The size of martensite lamellae is diversified as they are formed independently through repeated inhomogeneous primary and secondary shearing of the austenite lattice.

Conservation of invariant austenite-lamellar martensite inter-phase surface is the cause for which the martensite subjected to intensive deformations is characterized with high fine-graininess and has extremely high density of lattice defects (dislocation forest) [5–9].

The objective of this paper is to present the influence of cold plastic strain by rolling at room temperature, occurring in sheet chromium-nickel austenitic steel AISI 304L on α′ martensite content in the metal’s structure.

2. The material and the research methodology

Plastic strain at room temperature was applied to samples of 4-mm thick sheet AISI 304L steel chemical composition of which was determined by means of optical emission spectrometer Q4 TASMAN (Bruker)[1]. Chemistry of the tested sheet steel is following: 0,031%C, 0,40%Si, 1,78%Mn, 0,28%Mo, 18,0%Cr, 7,96%Ni.

Before being subjected to strain, all samples of the steel were annealed in N61/H furnace by Nabertherm GmbH at temperature 1150°C for 0.5 h and cooled, together with the furnace, at the rate of 40°C/h down to temperature of about 600°C, and then in air to room temperature.

Samples of sheet AISI 304 L steel annealed this way with dimensions 4 mm × 15 mm × 100 mm were rolled longitudinally at room temperature with the use of a modernized two-high mill by Vulkan Wien (Figure 1).The rate of deformation of the samples was about 300 mm/s.

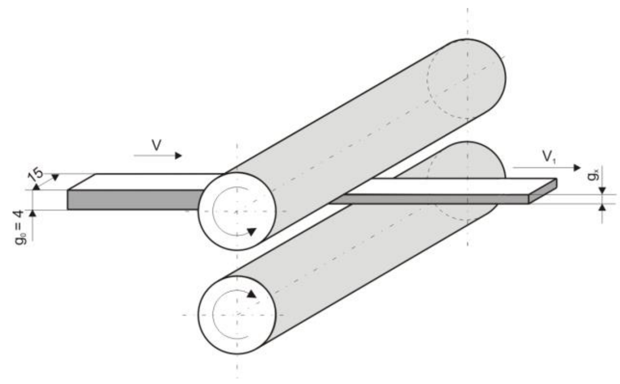

Fig. 1. Schematic of the cold roll process appliced to samples

The rolling was carried out with sample thickness being reduced by 0.2 mm after each subsequent passage between the rolls. Relative strain (cold work) obtained by rolling ε_{CR} was determined from the relationship,

$$\varepsilon_{CR} = (g_0 - g_x) / g_0 \times 100\%, \tag{1}$$

where: g_0 = 4 mm is the initial thickness of the sample and g_x is the sample thickness measured after a determined absolute deformation, $\Delta g = g_0 - g_x$.

As a result of cold rolling executed this way, material after plastic strain was obtained with relative cold work ranging from 5% (Δg = 0.2 mm) to 90% (Δg = 3.6 mm).

Content of α′ martensite in AISI 304L steel samples subjected to cold plastic strain by rolling was determined by using FERITOSCOPE FMP30 (Fischer).

Microstructure of the sheet metal after reaching different values of the degree of cold work was examined on metallographic sections by means of metallographic optical microscope Neophot2 and SEM multiscan V.08 VEGA3 (TESCAN) coupled with INCA X-ACT (Oxford)[2] attachment for X-ray microanalysis.

Metallographic sections prepared by means of mechanical polishing were electrolytically etched at voltage of about 5 V in solution containing 10 g $C_2H_2O_4$ + 90 ml H_2O and in the Kalling's etchant.

3. Test results and analysis

3.1. Cold rolled samples

Figure 2 shows a view of AISI 304L steel samples after cold rolling with different degree of cold work ranging from 5% to 90% obtained at constant strain rate of about 300 mm/s.

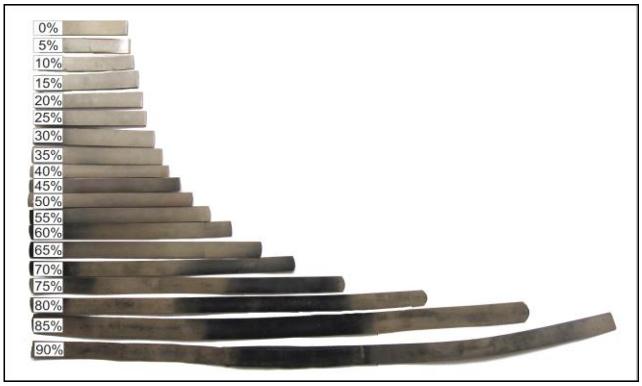

Fig. 2. A top view of longitudinally cold rolled sheet AISI 304L steel samples with different degree of cold work ranging from 5% to 90%

Longitudinal rolling of the samples results in elongation increase proportional to the degree of cold plastic strain accompanied by a slight broadening. The α′ martensite phase content in samples deformed shown in Figure 3.

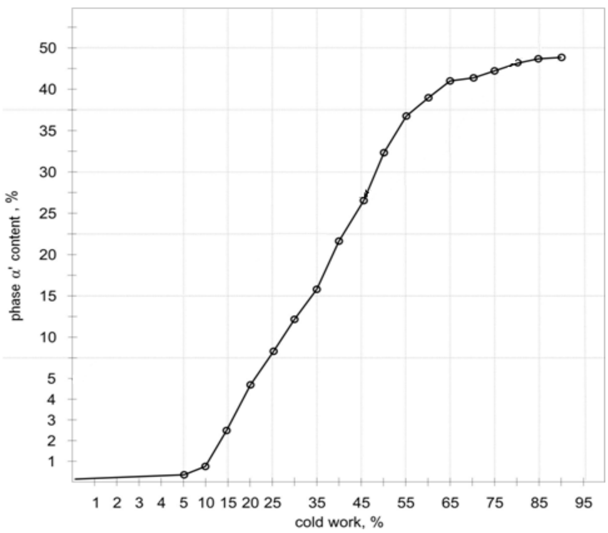

Fig. 3. Influence of the degree of cold work on α′ martensite content for AISI 304L steel

Together with linear increase of the degree of plastic strain of cold rolled AISI 304L steel sheet samples, α′ martensite content in the steel increases nonlinearly. The course of the changes is depicted by sign of the integral ∫. Plastic strain in the range from 0% to 10% induces some small increase of martensite content amounting to about 0.08% α′ per 1% cold work. Larger strain values in the range 10–55% create favorable conditions for increase of martensite content amounting to about 0.8% α′ per 1% cold work. Intensive non-dilatational and dilatational strain of austenite occurring at high rate and increase of the energy stimulate nucleation and growth of twinned martensite lamellae. The largest strain values ranging from 55% to 90% slow down the increase of martensite content to the level of about 0.35% α′ per 1% of cold work as an average.

3.2. Microstructure of rolled samples

Example microstructures of AISI 304L steel sheet samples in the annealed and cold rolled conditions with strain values 10% and 90% are shown in Figures 4-6.

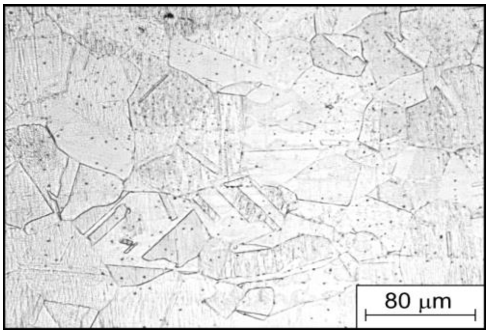

Fig. 4. Microstructure of sheet AISI 304L steel after annealing. Equiaxial and twinned γ austenite grains. Optical microscope

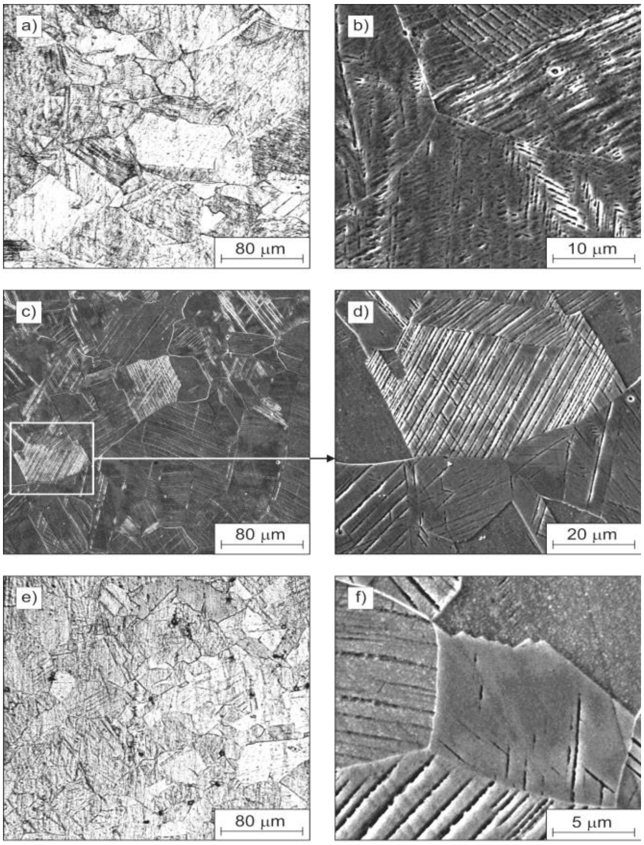

Figure 5. Microstructure of sheet AISI 304L steel after annealing and cold rolling with the degree of cold work of 10%: on the cross-section perpendicular to rolling direction as seen in optical microscope (a) and SEM (b, c, d); and on the cross-section parallel to rolling direction as seen in optical microscope (e) and SEM (f). Twinned grains of γ phase, about 0.8% of α′ martensite

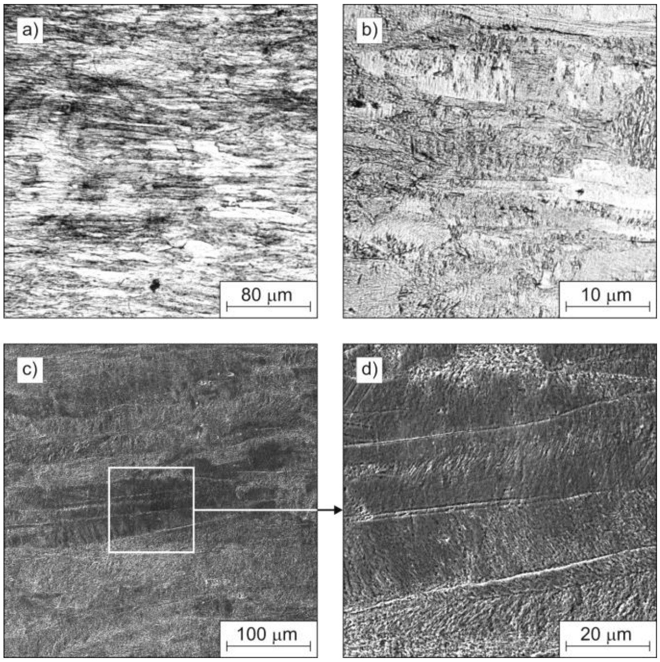

Figure 6. Microstructure of sheet AISI 304L steel after annealing and cold rolling with cold work of 90% on: (a) the cross-section perpendicular to rolling direction; and (b) on the cross-section parallel to rolling direction as seen in optical microscope. Panels (c) and (d) show the same in SEM. About 48% of twinned α′ martensite lamellae with characteristic midrib

4. Summary

Annealed 4-mm thick samples of sheet AISI 304L steel were subjected to plastic strain at room temperature by rolling at 300m/s. At a result of the study it has been found that:

- linear increase of the cold work induced by plastic strain occurring in the course of cold rolling in the range from 0% to 90% results in a nonlinear increase of content of the strain-induced lamellar α′ martensite in the steel's microstructure varying from 0% to 48%.

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