

# Martensite Content and Mechanical Properties of Uniaxial Tension AISI 304L Steel

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Received 31.03.2014; accepted in revised form 14.04.2014

## 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  $\alpha'$  martensite in its structure. The strain was introduced by uniaxial tension with constant strain rate of about 0.083 mm/s. It has been demonstrated that the share of  $\alpha'$  martensite in microstructure of the steel determined by means of Feritscope FMP30 in the time at uniaxial tension.

**Key words:** 304L austenitic steel, Uniaxial tension, Martensitic phase

## 1. Introduction

When the metastable austenitic steels are subjected to cold plastic strain, athermal martensitic transition proceeds in austenite grains.

Observations reveal also that martensite contains glide bands or deformation twins with thickness less than 0.001 mm. A detailed analysis allows to state that between austenite and martensite grains there can be only one macroscopically invariant plane with indices (259). This plane coincides with the habit plane observed in martensite created in temperatures lower than or close to the room temperature [1]. At the moment of creation, martensite lamellae have flat side surfaces and are composed only of internally twinned areas constituting the so-called midrib. In outer portions of the lamellae, the lattice maintaining the strain unchanged is realized by gliding. TEM observations of thin foils show that in these regions, density of dislocations may reach values of the order of  $10^{16}$ – $10^{17}$  m<sup>-2</sup> [2].

The quantity of lamellar martensite crystals induced by plastic strain occurring in metastable chromium-nickel austenitic steels depends on their chemical composition, stress magnitudes, temperature, and the degree of strain [3, 4, 5].

The objective of this paper is to present the influence of cold plastic strain in the time of uniaxial, tension, at room temperature chromium-nickel austenitic steel AISI 304L on the mechanical properties and  $\alpha'$  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)<sup>1</sup>. 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, Nabetherm 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.

Annealed AISI 304 L steel samples with the shape shown in Figure 1, were subjected to cold strain by application of uniaxial tension. The tension test was carried out at constant strain rate, 5 mm/min (about 0.083 mm/s) with the use of Zwick/Roell Z100 testing machine.

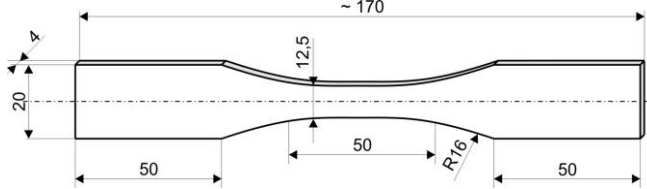


Fig. 1. Shape of samples subjected to uniaxial tension

Content of  $\alpha'$  martensite in AISI 304L steel samples subjected to cold plastic strain by application of uniaxial tension was determined by using FERITOSCOPE FMP30 (Fischer)<sup>2</sup>. Before measurements, the instrument was calibrated with the use of standards (%Fe-WCR 03-10, serial No. N1-0322, and %Fe-WCR 10-80, serial No. N2-0322). FERITOSCOPE FMP30 allows to measure content of ferromagnetic phases in microstructure of AISI 304L steel with accuracy of  $\pm 0.1\%$ . In samples subjected to tension, martensite  $\alpha'$  content has been determined in the middle of the measurement segment every 10 seconds in the course of deformation.

### 3. Test results and analysis

#### 3.1. Uniaxial tension

Figure 2 shows the curve representing uniaxial tension applied at room temperature to sheet AISI 304L steel samples with the shape shown in Figure 1. On the curve, characteristic drops of tension force can be observed (Fig. 2a, b, c). Content of  $\alpha'$  martensite values in the course of tension test measured in central regions of the sample's measuring section are represented by the curve shown in Figure 2d.

Further, Figure 3 shows a ruptured sample with values of phase  $\alpha'$  content measured along its length.

As a result of uniaxial tension applied to AISI 304L steel samples with the strain rate of 0.083 mm/s, plastic deformation and creation of  $\alpha'$  martensite starts after reaching the force of about 15000 N. At the strain value of about 5.5%, an abrupt drop of the tensile force can be observed on the tension curve (Fig. 2b). Further increase of the force and the related increase of sample strain to about 14.5% result in a second abrupt force drop by about 11000 N (Fig. 2c). Another abrupt, yet only half as deep drops of the tensile force value, are observed on the curve at strain values amounting to about 22%, 29% and 39%, (points 3, 4, and 5 in Fig. 2a).

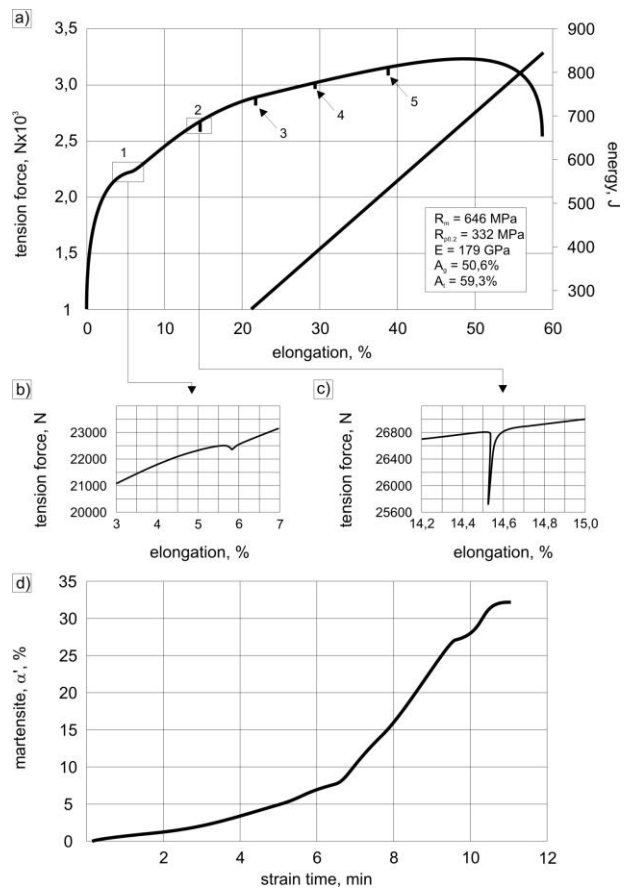


Fig. 2. The tension curve, mechanical properties: (a) samples of annealed sheet AISI 304L steel; (b) a detail of the curve section, region 1; (c) a detail of the curve section, region 2; (d)  $\alpha'$  martensite content in the course of strain

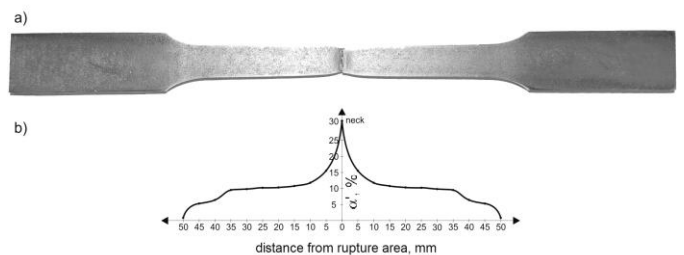


Fig. 3. Martensite content in a AISI 304L steel sample deformed by uniaxial tension

For creation of twinned  $\alpha'$  martensite it is necessary that a definite limiting shear stress value is reached that triggers movement of twinning dislocations. Such stress results in fast creation of martensite with a definite crystallographic orientation. Increasing and decreasing the tensile force in the course of

nucleation and growth of martensite twins is reflected in abrupt drops of the force value registered on the tensile curve.

### 3.2 Fractographic analysis

Fractures occurred after rupture of uniaxially tensioned AISI 304L steel samples reveal a ductile-brittle nature. The breaking starts within a neck created in the sample's middle portion, and the resulting fracture has the form of a "double saucer" (Fig. 4).

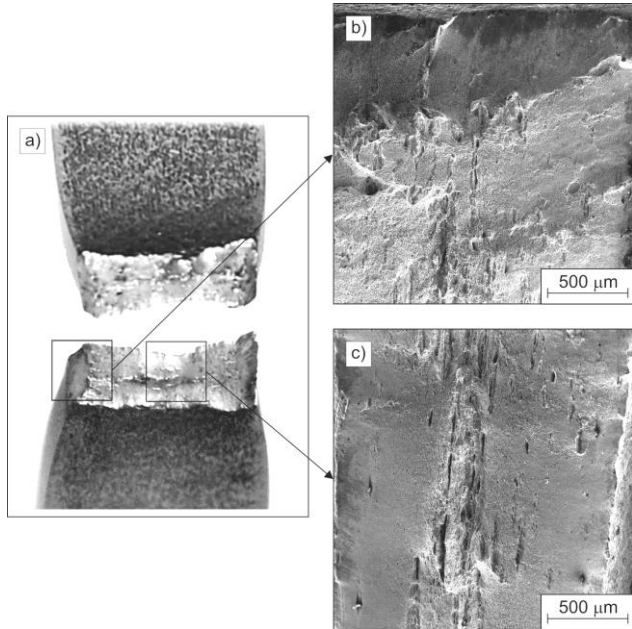


Fig. 4. Fractures of annealed AISI 304L steel samples subjected to uniaxial tension: (a) macrostructure of neck fracture in the form of a "double saucer"; (b) a view of the fracture as seen from the sample surface; (c) a view of the fracture in its central part.

In the region of the neck forming, as a result of concentration of intensive plastic strain, complex stress state, and fast growth of strain-induced  $\alpha'$  martensite, numerous cracks and voids nucleate and develop. Microcracks in the uniaxial tension conditions elongate along dominant axial stresses, and because of narrowing of the neck, they are subjected to elongation resulting in ultimate rupture. As a result of the process, a ductile fracture is formed with characteristic equiaxial hollows (Fig. 5).

In central portions of the "double saucer" area one can observe a ductile-brittle fracture with flat zones and glide line steps [6]. Patterns of cracks occurring in brittle regions are characteristic for transcrystalline cleavage cracking that propagates in mutually parallel and closely located crystallographic planes or cleavage planes, followed by occurrence of breaks, the so-called jogs, between them on the fracture surface. Additionally, secondary cracking between

primary cracks in cleavage planes occurs including creation of and breaking bridges as a result of intensive plastic strain (Figure [6]).

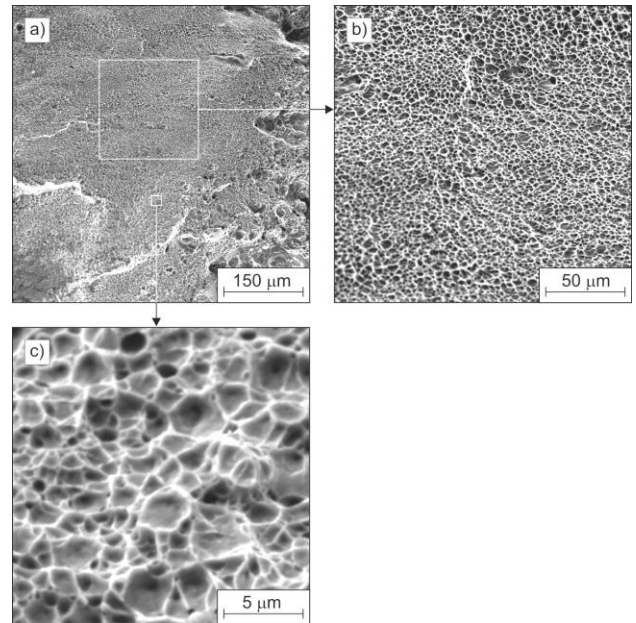


Fig. 5. Ductile fracture dominating in outer parts of the "double saucer" fracture of annealed AISI 304L steel samples

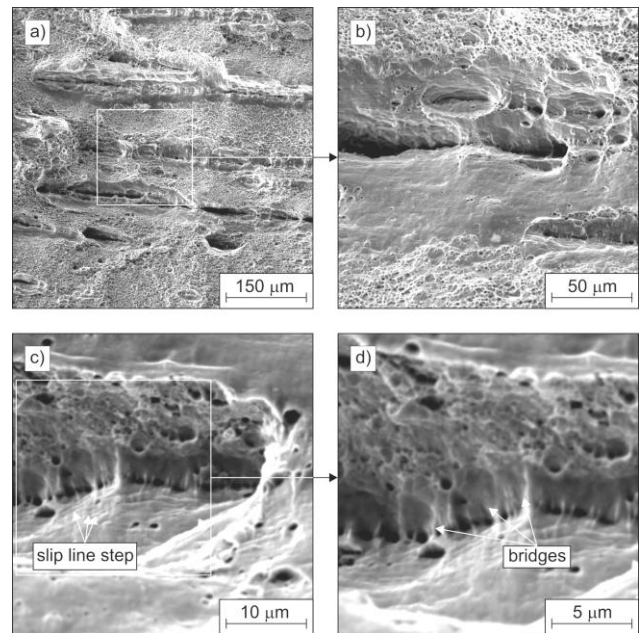


Fig. 6. Ductile-brittle fracture in the central region of the "double saucer" fracture of annealed AISI 304L steel sample subject to uniaxial tension: (a), (b) ductile and flat cleavage fracture areas; (c), (d) cleavage planes (glide line steps) with interlayer bridges

## 4. Summary

Annealed 4-mm thick samples of sheet AISI 304L steel were subjected to plastic strain at room temperature by uniaxial tension with strain rates at 0,083mm/s. At a result of the study it has been found that:

- in the course of the tensile test, the sheet metal is subjected to plastic strain that induces creation of lamellar  $\alpha'$  martensite crystals varying with the tested sample's measuring length.
- fractures occurred after rupture of tensioned samples have the shape of a "double saucer" with a predominance of ductile regions populated by equiaxial hollows and with brittle regions characterized by domination of cleavage cracks and tearing apart interlayer bridges running along  $\alpha'$  martensite twinning planes.

## Acknowledgements

1. The equipment was purchased under the project „Creation, development and modernisation of the scientific and research base of the Rzeszów University of Technology" within the framework of the Podkarpackie Voivodeship Regional Operational Programme for the years 2007-2013.

2. The apparatus was purchased under the project No. POPW.01.03.00-18-012/09 from Structural Funds provided in the framework of the Operational Programme 'Development of Eastern Poland' co-funded by the European Unions from the European Regional Development Fund.

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