Materials Science & Engineering A 624 (2015) 256–260

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Estimation of the kinetics of martensitic transformation in austenitic stainless steels by conventional and novel approaches

M. Shirdel [a], H. Mirzadeh [a,c,*], M.H. Parsa [a,b,c]

[a] School of Metallurgy and Materials Engineering, College of Engineering, University of Tehran, P.O. Box 11155-4563, Tehran, Iran
[b] Center of Excellence for High Performance Materials, School of Metallurgy and Materials Engineering, University of Tehran, Tehran, Iran
[c] Advanced Metalforming and Thermomechanical Processing Laboratory, School of Metallurgy and Materials Engineering, University of Tehran, Tehran, Iran

ARTICLE INFO

Article history:
Received 19 October 2014
Accepted 28 November 2014
Available online 5 December 2014

Keywords:
Deformation-induced martensite
Magnetic measurement
X-ray diffraction

ABSTRACT

A comparative study was carried out on the kinetics of the martensitic transformation in a 304L stainless steel during cold rolling by conventional and novel approaches. The phase analysis based on X-ray diffraction patterns and metallography and also magnetic measurements based on ferritescope readings were utilized to elucidate the kinetics of the martensitic transformation. A straightforward magnetic measurement approach for evaluating the amount of strain-induced martensite in metastable austenitic stainless steels has been introduced in this study. This technique collects the data throughout the bulk of the material to give a realistic estimate of the amount of ferromagnetic martensite. This is an advantage over the surface collecting methods such as ferritescope readings, which overestimates the amount of martensite due to its inhomogeneous distribution through the thickness based on the frictional effects between the rolls and the specimen surface. The proposed approach can be applied in various designs for static/continuous magnetic measurement of bulk materials that is advantageous compared with the conventional vibrating sample magnetometer technique which is useful for static measurement of bulk materials with specific shapes. Moreover, in analogy to ferritescope, the output data of the developed device is directly related to the amount of martensite.

1. Introduction

It is well-known that when an austenitic stainless steel is deformed at a certain range of temperatures, it transforms from fcc austenite (γ) to ferromagnetic bcc martensite (α') [1,2]. The amount of the martensite greatly influences the mechanical and physical properties of AISI 304L stainless steel. Accordingly, an accurate determination of the volume fraction of strain-induced martensite is essential. The most common measurement methods are based on the phase detection by X-ray diffraction (XRD) and ferromagnetic property of the α'-martensite phase. Mössbauer spectroscopy, neutron diffraction, and density measurement are also reported as alternative techniques [3–7]. Magnetic methods are based on the measurement of magnetic force acting on the sample placed in a magnetic field. The vibrating sample magnetometer is conventionally used for static measurement of the magnetic property of bulk material by plotting the magnetization or B–H curve of the material [8]. Ferritescope is another magnetic device that has been used in many investigations for quantitative measurement of strain-induced martensite. The XRD and ferritescope techniques collect the data from a limited depth of the specimen surface, while it is well-known that the amount of strain-induced martensite decreases from the surface to the center of the rolled sheet specimen [3]. The XRD technique is also expensive, time consuming, and suffers from the adverse effect of the presence of texture [9].

The aims of this work are to conduct a comparative study between different approaches and to present a new approach and device to study the static/continuous measurement of martensitic transformation based on the magnetic permeability determined from the bulk of the material. This approach could be applied in many designs for a various shape of the material in industrial applications.

2. Experimental materials and procedures

Commercial type 304L stainless steel with chemical composition of 0.023 wt% C–18.47 wt% Cr–8.05 wt% Ni-0.476 wt% Si–1.43 wt% Mn–0.09 Mo–0.003 wt% Ti–0.129 wt% V–0.128 wt% Nb was used in this study for formation of strain-induced martensite to

* Corresponding author at: School of Metallurgy and Materials Engineering, College of Engineering, University of Tehran, P.O. Box 11155-4563, Tehran, Iran. Tel.: +98 2182084127; fax: +98 2188006076.
E-mail addresses: mshirdel1989@ut.ac.ir (M. Shirdel), hmirzadeh@ut.ac.ir (H. Mirzadeh), mhparsa@ut.ac.ir (M.H. Parsa).

http://dx.doi.org/10.1016/j.msea.2014.11.087
0921-5093/

compare conventional measurement methods with the developed approach. Strain-induced martensite is a controllable ferromagnetic phase, which can be used to evaluate the capability of the proposed approach. Rectangular strips, $100^{L} \times 30^{W} \times 1.2^{t}$ mm^3 were used for rolling. The specimens were subjected to cold rolling at room temperature to achieve reductions in thickness (equivalent strain) of 25% (0.370), 35% (0.590), 45% (0.707), 55% (0.922) and 65% (1.103). For each reduction, six specimens were repeated. Three specimens of each reduction were pickled in a solution containing 15% HNO_3 (65 percent strength), 10% HF (50% strength) and 75% water to dissolve the approximately 10% of the surface layer [10,11]. Since the surface of the sheet senses a higher strain due to the frictional effects resulted from the rolls, the sufficient surface removal operation is needed and resulted in a homogeneous distribution of the strain induced martensite through the thickness of the samples [4]. This is an extra requirement to achieve more reliable results from XRD and ferritescope, which is neglected in most of the investigations.

Standard metallographic techniques were employed for the preparation of samples for optical microscopy (OM) and scanning electron microscopy (SEM). The mixture of a solution containing 0.15 g $Na_2S_2O_5$ solved in 100 ml distilled water and a solution containing 10 ml HCl solved in 100 ml water [4] was used as the etchant to reveal the strain-induced martensite phase in the microstructure. The Vickers hardness test was performed using a load of 5 kg to inspection of how the strain-induced martensitic transformation affects the mechanical properties.

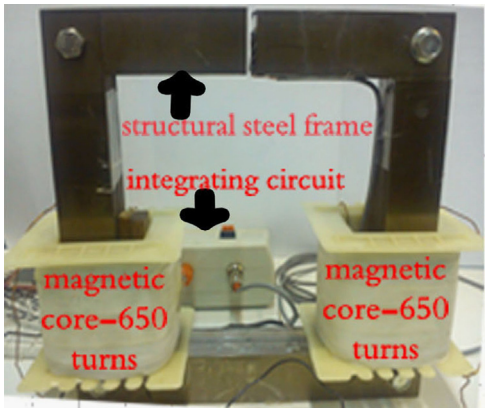

Fig. 1. The developed magnetic device.

3. Magnetic approach and the developed device

Fig. 1 shows the developed magnetic device. As can be seen, the device is composed of three major units: (I) the magnetic cores

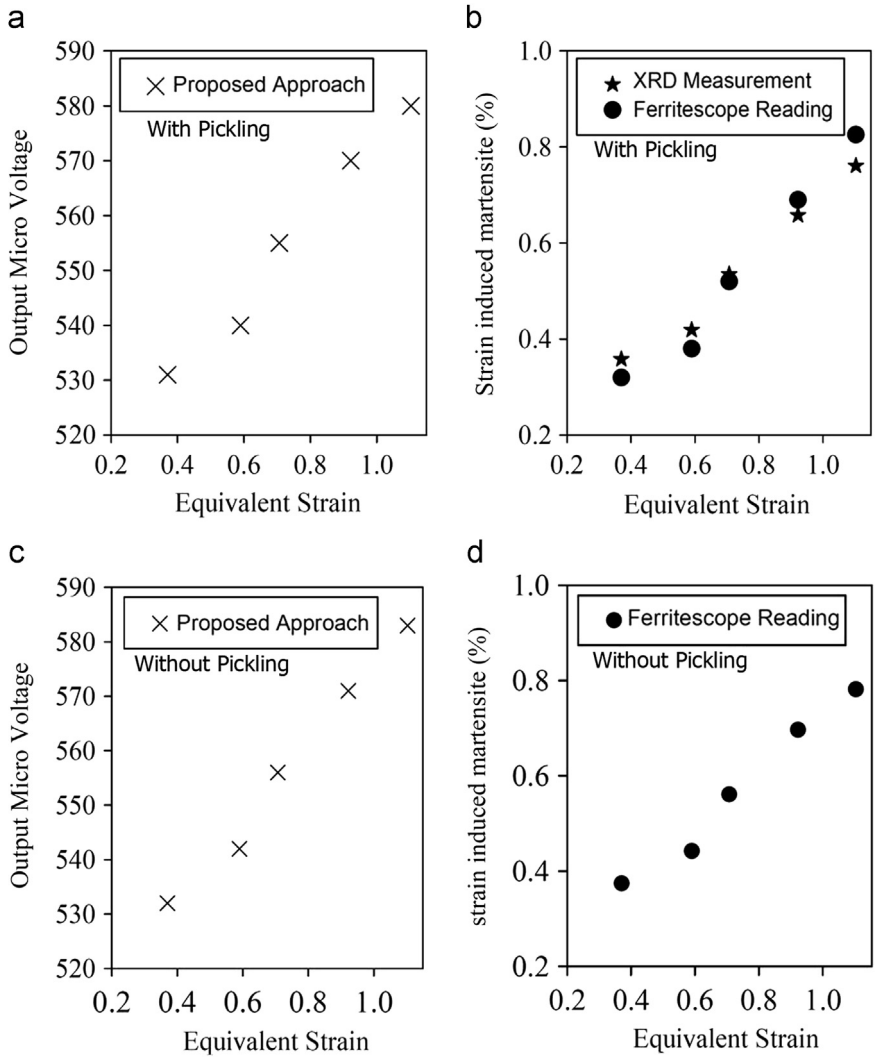

Fig. 2. Output voltage of the developed device and the corresponding XRD phase analysis and ferritescope readings versus the equivalent rolling strain.