Materials and Design 30 (2009) 3869–3872

Contents lists available at ScienceDirect

Materials and Design

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

Short Communication

Potential application of nanocrystalline 301 austenitic stainless steel in lightweight vehicle structures

M. Eskandari *, A. Najafizadeh, A. Kermanpur, M. Karimi

Department of Materials Engineering, Isfahan University of Technology, Isfahan 84156-83111, Iran

ARTICLE INFO

Article history:
Received 26 January 2009
Accepted 31 March 2009
Available online 5 April 2009

ABSTRACT

In recent years, nano/ultrafine grained steels have been the focus of great attention for the construction of lightweight structures. In this work, the effects of thermo-mechanical parameters were investigated in order to achieve a nanocrystalline structure in the as-cast AISI 301 stainless steel. A minimum grain size of 18 μm was initially achieved when homogenization took place at 1200 °C for 9 h followed by hot rolling at a temperature range of 1000–1200 °C with a strain value of 0.8 and a strain rate of 1.2 s^{-1}. The product was then annealed at 1050 °C for 3 min. In order to get a nanocrystalline structure, repetitive cold rolling followed by subsequent annealing was used. The cold rolling was carried out at a temperature of −10 °C with a strain rate of 0.5 s^{-1} and a reduction of 95%, while the annealing treatment was conducted at temperatures of 600 to 850 °C for 0.5 to 50 min. The results showed that the nanocrystalline austenitic structure with a grain size of about 70 nm was obtained by annealing at 850 °C for 1 min after an overall cold rolling reduction of 95%.

1. Introduction

Passenger protection in vehicle crashes is directly related to the crush avoidance systems, passive safety devices, and crashworthiness structures to reduce injury risks to passengers. The vehicle's structural capability to manage the impact energy represents the main line of defense. Vehicle mass reduction and high structural crashworthiness, energy saving, and safety demands presently form the major concerns of automakers who try to use materials that make vehicles safer and lighter. Lightweight vehicles, in fact, mean savings in fuel and reduction in exhaust emissions to conform to environmental regulations. The material traditionally used in car bodies is carbon steel which offers such advantages as ease of manufacturing, energy absorption, and relatively low costs [1]. However, over the past years, the requirement to meet new standards and targets such as weight reduction (fuel economy), durability, low noise and vibration, and harness have created interest in substitution of materials. The only alternative to the conventional carbon steels is light materials such as composite materials. Nevertheless, these involve problems of cost and weldability. Compared with carbon mild steels, austenitic stainless steels enjoy excellent formability, weldability, work hardening properties, high corrosion resistance, high energy absorption capabilities, and many other advantages that make them potential substitutes for structural materials. High energy absorption capabilities contribute significantly to vehicle's passive safety reducing road injuries and fatalities. Austenitic stainless steels have cold working properties, ideal for hydro-forming by both sheet and welded tube. These steels are easy to weld by any traditional technique and do not need painting treatment because of their corrosion resistance. Even if painting is required for aesthetic appeal to consumers, the steel surface must only be degreased and painted by cataphoresis as these steels are inert to phosphatizing. The nanocrystalline structure of these steels in structural applications yields not only better corrosion resistance but also weight reduction and improved crashworthiness. Fig. 1 shows the comparison of carbon steels and austenitic stainless steels. As shown, stainless steels exhibit higher yield strength and elongation. Under the same geometry, a vehicle component made of austenitic stainless steels presents higher energy absorption capabilities than that of mild carbon steel, just because of the excellent work hardening properties of such materials and their high strain sensitivity. These steels, therefore, provide an effective solution as substitutes for carbon steel as a structural material when enhanced formability, rigidity, and crash behavior are required.

Among the austenitic stainless steels, the 301 steel has the highest work hardening rate and is the best nominee as a substitute material. Such steels are thermodynamically metastable austenite at room temperature, and are easily transformed to martensite (strain-induced martensite, SIM) with deformation below the M_d temperature. With increasing strain, the volume fraction of SIM increases. The martensite formation becomes supersaturated at a specific strain called 'supersaturating strain' (ε_s). The martensite crushes during deformation, increasing lattice

---

* Corresponding author. Tel.: +98 9166163982; fax: +98 311 3912752.
E-mail addresses: farzad_eskandary@yahoo.com (M. Eskandari), a-najafi@cc.iut.ac.ir (A. Najafizadeh), ahmad_k@cc.iut.ac.ir (A. Kermanpur).

0261-3069/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2009.03.043

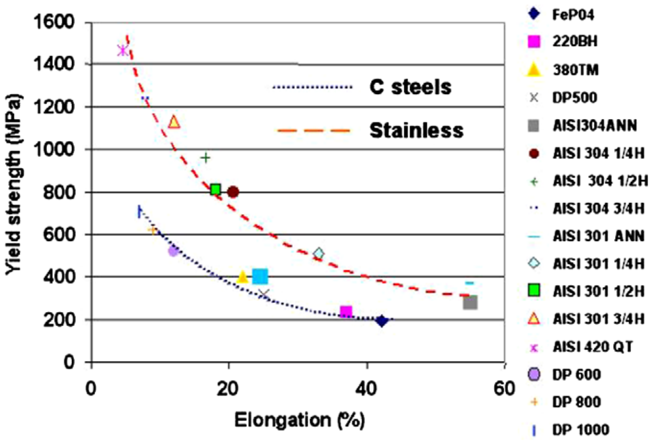

Fig. 1. Comparison of carbon steels and stainless steels [1].

defect inside SIM. Finally, the martensite is reverted to austenite during subsequent annealing, leading to noticeable grain refinement [2–5].

It is the objective of the present study to enhance the specific strength of a 301 austenitic stainless steel by creating a nanocrystalline structure after conventional cold rolling followed by annealing treatment.

2. Materials and experimental procedures

Cast ingots of AISI 301stainless steel were prepared using an induction furnace under air atmosphere with chemical composition (in wt.%) of Fe–0.11C–0.67Si–0.65Mn–16.30Cr–6.91Ni–0.27Mo–0.003Nb. The as-cast grain size was about 1010 ± 100 μm that was decreased to 18 μm after homogenization for 9 h and hot rolling at a temperature range of 1000–1200 °C with a strain value of 0.8 and a strain rate of 1.2 s^{-1} (Table 1) followed by annealing at 1050 °C for 3 min. To obtain the nanocrystalline structure, a repetitive thermo-mechanical process was used as shown in Fig. 2. Multi-pass cold rolling was carried out at temperatures −196, −10 and 0 °C with a strain rate of 0.1 and 0.5 s^{-1} and a thickness reduction of 95%. The first and second annealing treatments were carried out at 750 °C for 10 min and at a temperature range of 600–850 °C for 0.5 to 50 min, respectively. The microstructures were observed using a scanning electron microscope (SEM Philips X230) after electro-etching in 65% nitric acid solution. Hardness of the samples was measured by Vickers method (HV) with the indenting load of 10 kg. Also the amount of magnetic phase was determined using a Feritscope MP30. The dilatometric method was used to determine the M_s temperature of 301 steel after carbide precipitation during annealing treatment. The sample was heated with the rate of 7 °C/s to 850 °C and kept at this temperature for 100 min; the sample was then cooled with the rate of 3 °C/s to room temperature.

Table 1
The rolling schedule used in this work.

Pass number	Strain	Strain rate (s^{-1})	Temperature (°C)
1	0.13	1.2	1200
2	0.13	1.2	1100
3	0.13	1.2	1010
Reheating in furnace for 2 min at 1200 °C			
4	0.2	1.2	1200
5	0.2	1.2	1020

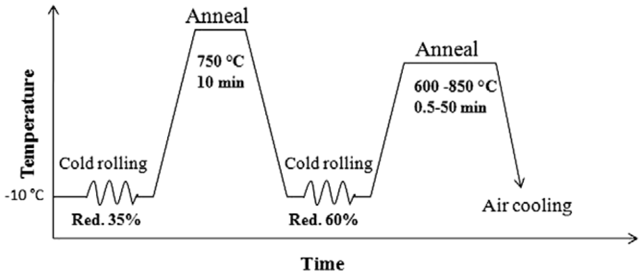

Fig. 2. Diagram of the repetitive thermo-mechanical process to obtain nanocrystalline 301 stainless steel.

3. Results and discussion

The effects of rolling temperature, strain rate and strain on the volume percentage of the SIM during cold rolling are shown in Fig. 3. As shown in Fig. 3a, at a rolling temperature of 0 °C, the volume fraction of SIM reached 100% at a thickness reduction of 50%. Under this condition, ε_s was 0.7. At −196 °C (liquid nitrogen), saturation occurred at a thickness reduction of 20% and ε_s decreased to 0.2. Decreasing ε_s with reduced rolling temperature is attributed to the decrease in the stacking fault energy (SFE) and, consequently, to the increased available chemical driving force for the transformation [6,7]. Austenitic stainless steel has low stacking fault energy (SFE), and thus bundles of faults readily form during cold deformation. SFE plays an important role in determining the austenite stability since it controls the formation of shear bands and, thereby, the formation of nucleation sites for the martensite. It is seen in Fig. 3b that the volume fraction of SIM increases with increasing reduction (or strain) and strain rate. The reason for this lies in the intersection of shear bands as nucleation sites for martensite nuclei by increasing the strain and strain rate. Talonen et al. [7] showed the inverse effect of the strain rate on the martensite formation due to the adiabatic heating occurred during cold

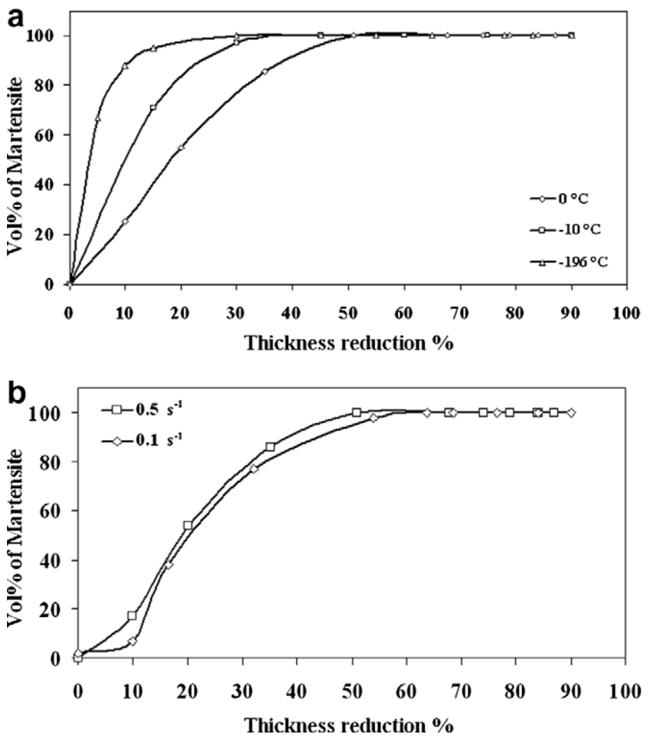

Fig. 3. Effects of deformation parameters on the martensite formation: (a) rolling temperature and (b) strain and strain rate.