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Correlation between Luder strain and retained austenite in TRIP-assisted cold rolled steel sheets

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Abstract

In developed multiphase high strength, high formability TRIP-aided steel, Luders bands are observed similar to conventional low carbon steels. Retained austenite as the most effective constituent in TRIP steels, is responsible for Luders band formation as well as other properties such as formability, physical and mechanical properties.

In the present study, a correlation between the Luders strain and the retained austenite characterization is proposed and verified by experimental evidences of the work carried out on two types of TRIP steel sheets. Intercritical annealing of cold rolled TRIP steels at different temperatures change the volume fraction of the retained austenite as well as the carbon concentration of samples which in turn leads to different Luders strain values. The experimental results show that the Luders strain is limited when the volume fraction and carbon concentration of the retained austenite increase in the TRIP steels.

Keywords: TRIP steel; Retained austenite; Luders strain; Intercritical annealing; Cold rolled sheet

1. Introduction

Formation of Luders bands is a well known phenomenon in metallic materials, especially in low carbon steels, and has been studied by many researchers [1–3]. Interstitial dissolved elements such as carbon, nitrogen and boron in steel are responsible for the stretching strains by locking the dislocations and by formation of Cottrel–Bilby atmosphere [4,5]. As the appeared Luders bands on the surface of the product in sheet forming operation are undesirable, identification of material and processing characterization for elimination of Luders bands is very important [6].

Recently, multiphase transformation induced plasticity (TRIP) assisted steels have been improved as a new innovation of low alloy high strength steels with exceptional formability [7–9]. Cold rolled TRIP steel sheets are good candidates for automotive industries [10,11]. The Luders strain is observed on the stress–strain curves of the intercritically annealed TRIP-aided steel sheets [11–13]. Very limited investigations have been done on the mechanism of formation of Luders band in this type of steels. The effect of many factors such as chemical composition of steel, intercritical annealing temperature, austempering time and temperature which all determine the volume fraction and carbon concentration of retained austenite should be systematically experimented for minimizing the stretching strain.

In the present work, two types of TRIP steels with different compositions were chosen and the effect of intercritical annealing temperature on the Luders strain was investigated by tensile test. The Luders strain is correlated to the volume fraction of the retained austenite and its carbon concentration.

2. Experimental work

Chemical composition and critical temperatures of two utilized TRIP steels are shown in Table 1. The critical temperatures (A_{c1} and A_{c3}) were obtained by dilatometery.

The processing scheme of materials is illustrated in Fig. 1. Hot bands with thickness of 2.7 mm were hot rolled with a finish rolling temperature (FRT) at 950 °C. After descaling, specimens were cold rolled to the thickness of 0.6 mm with 76% reductions in height. Intercritical annealing was performed on cold rolled sheets at 760, 810 and 860 °C for 5 min and then the samples were held in salt bath at 400 °C with 3 min holding time and finally air cooled.

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Table 1
Chemical composition and critical temperatures of the materials

Sample code	Chemical composition [in wt%]						A_{c1} [°C]	A_{c3} [°C]
	C	Mn	Si	P	S	Al		
Si-TRIP	0.12	1.60	1.28	0.015	0.002	0.05	748	897
Al-TRIP	0.27	1.48	0.28	0.015	0.001	1.08	746	970

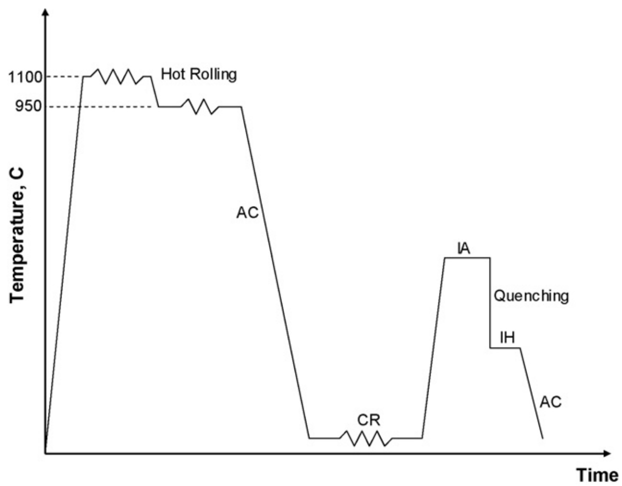

Fig. 1. Schedule of experimental work on the TRIP steels (AC, air cooling; CR, cold rolling; IA, intercritical annealing; IH, isothermal holding).

Standard size tensile specimens were machined in the rolling direction (RD), 45° to RD and transverse direction (TD). Tensile tests were carried out at room temperature with average strain rate of 0.001 s^{-1}. The volume fraction of retained austenite was measured by X-ray diffraction using Cu-tube radiation.

The volume fraction of retained austenite was calculated by comparing the integrated intensities of $(2\,2\,0)_\gamma$ and $(3\,1\,1)_\gamma$ peaks with intensity of the diffracted X-ray from the $(2\,1\,1)_\alpha$ planes of ferrite [14]. The calculation procedure of the volume fraction of retained austenite has been presented by the authors elsewhere [15]. The carbon concentration ($C_{(\mathrm{wt\%})}$) of retained austenite was calculated by the following equation [16].

$$a\,(\mathrm{\AA}) = 3.580 + 0.0330 C_{(\mathrm{wt\%})} \quad (1)$$

where a in Angstrom is the lattice constant of the retained austenite which is measured by XRD and Barge's diffraction law.

3. Results and discussion

Some of the stress–strain curves of the RD samples at different annealing temperatures are typically shown in Fig. 2.

The appearance of yield point discontinuity and the extent of yield point elongation which is observed in some cases (sharply in the annealed sample at 760 °C and slightly in the sample annealed at 810 °C), are related to the retained austenite characteristic and will be discussed later. More experiments and observations are needed to verify the effect of retained austenite and microstructure during intercritical annealing on mechanical properties of the TRIP-aided steels.

Luders strains were measured on the stress–strain curves of all samples at different directions with different processing conditions. Fig. 3 illustrates the anisotropy of Luders strain in the sheet plane.

It is observed that Luders strain has an anisotropic character in steels which essentially are amenable to aging and there is a plateau in their stress-strain curves. For Al-TRIP sheet annealed at 760 °C, the Luders strain varies from 2 to 4.5% at RD to TD direction (Fig. 3a). Similar result, through with lower variations

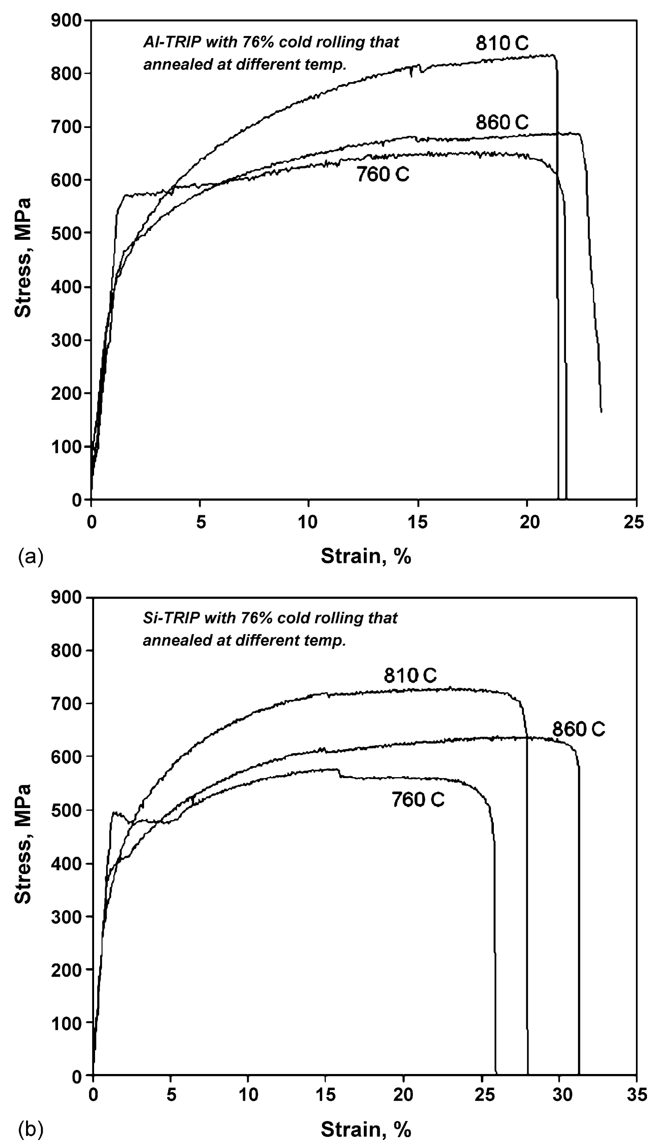

Fig. 2. Typical stress–strain curves of the samples at RD direction with different intercritical annealing temperatures for: (a) Al-TRIP and (b) Si-TRIP steels.