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Short communication

Control of retained austenite morphology through double bainitic transformation

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ABSTRACT

The feasibility controlling the morphology of retained austenite in TRIP steel was investigated utilizing double bainitic transformation which is two-step isothermal heat treatment. The change in morphology of the retained austenite from a blocky to film type improved the tensile properties owing to higher mechanical stability of film-like retained austenite.

1. Introduction

Transformation induced plasticity (TRIP) - assisted steels with retained austenite have drawn a great deal of attention for automotive sheets due to their excellent combination of strength and elongation [1–5]. In recent years, many researchers have attempted to develop enhanced TRIP steels with high manganese content by increasing the fraction of retained austenite [6–10]. The effect of characteristics of the retained austenite on the mechanical stability against plastic deformation in TRIP steel has been an important concern. It has been generally reported that film-like retained austenites are more stable than blocky retained austenites due to higher carbon enrichment and a morphology effect. Furthermore, it has also been argued that film-like retained austenite is too stable for TRIP to occur [3,11–17]. Furthermore, a couple of approaches involving multi-step isothermal heat treatment to control the morphology of retained austenite have been introduced to improve the mechanical properties. Hase et al. [18] showed that tensile properties and fracture toughness were improved as a result of eliminating blocky austenites and inducing nanostructured plates of bainitic ferrite by adopting a two-stage heat treatment. Wang et al. [19] reported a significant increase of strength and charpy impact toughness without sacrificing ductility by inducing blocky retained austenites to finer bainite through two-step heat treatment. These works reported improved mechanical properties using high or medium carbon and high alloying steels, both of which were heat treated at quite low temperature in a range of 200–350 °C to acquire nanostructured bainitic ferrite and film-like retained austenite.

In this study, the feasibility controlling the morphology of retained austenites and thereby improve mechanical properties by a two-step isothermal heat treatment that can be applied to commercial products was explored with TRIP assisted steel containing simple chemical composition such as C, Mn, and Si. In addition, the effect of the morphology of the retained austenite on the mechanical stability against plastic deformation was directly investigated using small tensile specimens customized to a deformation stage for on-site EBSD (Electron-BackScattered Diffraction) analysis.

2. Experimental

The chemical composition of the examined steel was Fe–0.30C–1.5Mn–1.5Si (in wt%), which was similar to that of simple C–Mn–Si steels reported in previous studies [11,20]. The steel was prepared using a vacuum induction melting furnace and a 30 kg ingot was

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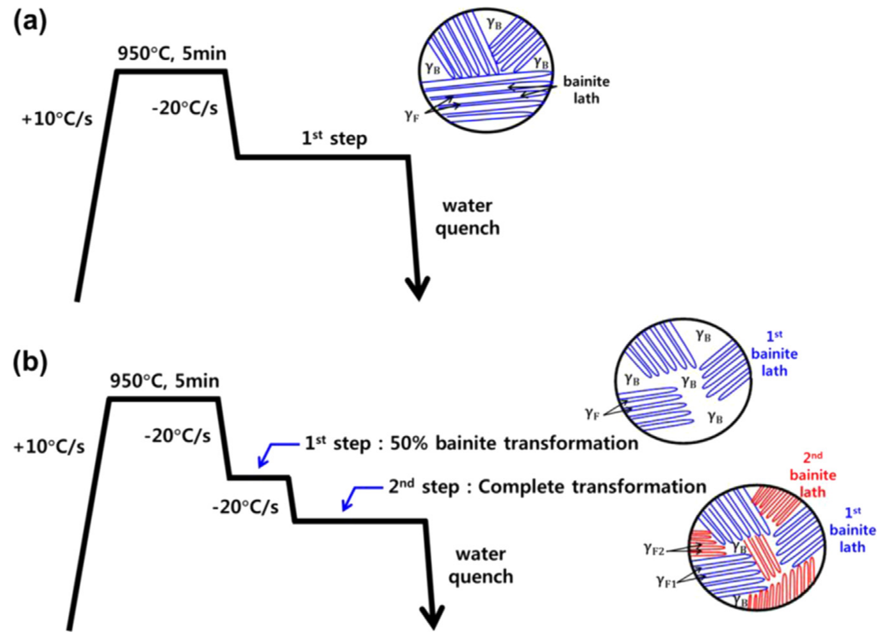

Fig. 1. Schematic diagrams representing heat treatments and microstructural evolutions: (a) single-step heat treatment and (b) two-step heat treatment.

Table 1
Heat treatment conditions of single-step and two-step heat treatments.

Specimens	Single-step heat treatment	Two-step heat treatment
Single-step	400 °C, 300 s	–
Two-step	500 °C, 20 s	400 °C, 280 s

hot rolled to 3 mm thickness. Dilatometry specimens were austenitized at 950 °C for 5 min, followed by isothermal heat treatment between bainite (Bs) and martensite (Ms) transformation start temperatures using a dilatometry machine (Theta, Dilatronic-III). Based on the experimental time-temperature transformation (TTT) diagram of this steel, stick specimens were also austenitized at 950 °C for 5 min and isothermally heat-treated by single-step or two-step processes between Bs and Ms temperatures using a Continuous Annealing Line (CAL) simulator (ULVAC, VHC-P616CP). The Bs [21] and Ms [22] were calculated to be 614 °C and 349 °C, respectively. The cooling rate between austenitization and isothermal heat treatment was 20 °C/s, which prevents of ferrite transformation during cooling. A schematic representation of the heat treatment cycles of single-step and two-step processes and of the behavior of the transformation to bainite during both heat treatments is illustrated in Fig. 1. Single-step and two-step heat treatments were performed at 400 °C for 300 s and at 500 °C for 20 s for 50% of transformation to bainite, followed by heat treatment at 400 °C for 280 s for completion of bainite transformation, respectively, as shown in Table 1. The specimens were characterized using scanning electron microscopy (SEM, JSM-7001 F, JEOL) and the EBSD technique for which a NordlysNano EBSD detector and AZTEC software from Oxford Instruments were used. Specimens for SEM were polished and etched using 1% nital solution (1 ml HNO3 + 100 ml ethyl alcohol), while those for EBSD were chemo-mechanically polished with colloidal silica without applying etching. To investigate on the mechanical stability of retained austenites according to their morphology, the progress of their transformation with strain increment was directly monitored in a strain range of 5–25%. Small specimens with dimensions of $11.5 \times 28 \times 2$ mm were strained in uniaxial tension using a custom-made deformation stage for the SEM in Fig. 2. Furthermore, on a fixed site of a specimen, consecutive EBSD mappings with strain increments were conducted. Finally, the enrichment of carbon in retained austenites was investigated by EPMA (JEOL, JXA-8530F operated at 15 kV and 15 nA beam current).

3. Results and discussion

Fig. 3 shows microstructures and tensile flow curves of the samples heat treated by single- and two-step processes. The microstructures produced by the single-step heat treatment at 400 °C

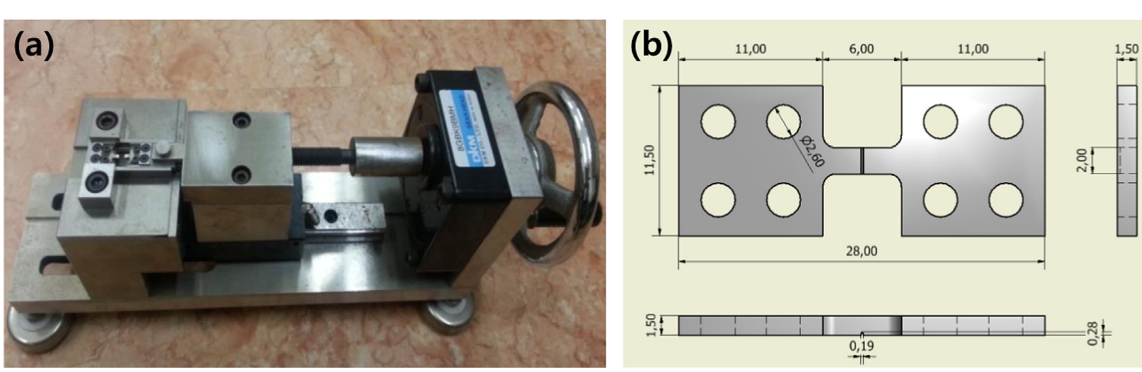

Fig. 2. Custom-made deformation stage (a) and dimensions of small tensile specimen (b).