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Effect of intercritical annealing on retained austenite characterization in textured TRIP-assisted steel sheet

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Abstract

Optimization of high strength and high formability of multiphase cold rolled sheet TRIP-aided steels is based on the composition and the austempering conditions. The effect of intercritical annealing temperature on the volume fraction and carbon concentration of the retained austenite was investigated in two different TRIP-aided steels. Experimental results show that the optimum annealing temperatures are 860 °C for Al-containing and 810 °C for Si-containing TRIP steels. It was demonstrated that the measurement of retained austenite can be successfully performed for textured TRIP steels by XRD.

Keywords: Intercritical annealing; TRIP steels; Retained austenite; X-ray diffraction

1. Introduction

The transformation-induced plasticity (TRIP) mechanism has been known as a useful method for development of new grades of steel with optimized high strength and good formability properties. Recently, cold rolled sheets of TRIP-assisted steels with high strength and suitable formability have been manufactured for the automotive industries in order to reduce the weight of engineering parts [1–3]. An enhancement of the formability of cold rolled TRIP-assisted steels is mainly determined by the characteristics of the retained austenite [4–8]. The chemical composition and such processing parameters as cold rolling, intercritical annealing and subsequent austempering treatment affect the volume fraction, distribution and carbon concentration of the retained austenite [8–14].

In this study, two types of TRIP steels were investigated. The effect of the intercritical annealing temperature after cold rolling on the retained austenite of the steels was studied. Some combinations of the diffraction peaks of the retained austenite permit measurement of its volume fraction; these have been utilized to establish a means for measuring the retained austenite in textured TRIP-assisted steels.

2. Experiment

Chemical compositions and the critical temperatures of the two TRIP steels studied here are shown in Table 1. The critical temperatures were obtained by dilatometry.

The initial materials, in the form of 20 × 12 × 2 cm blocks, were hot rolled to a thickness of 7 mm. By controlled rolling at a final rolling temperature (FRT)

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Table 1
Chemical composition and critical temperatures of the steels

Sample code	Chemical composition (in wt.%)						A_{c1} (°C)	A_{c2} (°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

of 950 °C, 2.7-mm-thick hot-rolled sheets were produced. After descaling, cold rolling was carried out to reduce the thickness by 76% to a final value of 0.6 mm.

Intercritical annealing was performed on the cold rolled sheets at 760, 810 and 860 °C. After a 5-min soak at these intercritical temperatures, samples were rapidly quenched in a salt bath at 400 °C, held there for 3 min, and then air cooled.

After mechanical polishing, the cold rolled sheets were etched with 2% nital. For the detection of retained austenite, the annealed and austempered samples were initially lightly etched with 2% nital and were then dipped in fresh sodium metabisulfite solution for 20 s. Samples from the midsection of the sheets were prepared by mechanical and electropolishing for X-ray diffraction by Cu radiation. A sample of Si-TRIP steel was also examined by XRD using Co radiation.

3. Results and discussion

3.1. Microstructural observations

The optical microstructures of the samples are shown in Fig 1. After intercritical annealing and subsequent austempering, retained austenite can be detected in both of the TRIP steels. Using a metabisulfite solution as the etchant reveals the retained austenite, ferrite, and bainite/martensite phases in white, gray and black contrast, respectively [15,16] (Fig. 1c and d).

3.2. Volume fraction of retained austenite

Figs. 2 and 3 show the X-ray diffraction patterns of the cold rolled and intercritically annealed Al-TRIP and Si-TRIP steels, respectively. Ferrite and probably martensite peaks are observed in the cold-rolled condition. By heat treating the cold rolled sheet and holding at isothermal condition, retained austenite

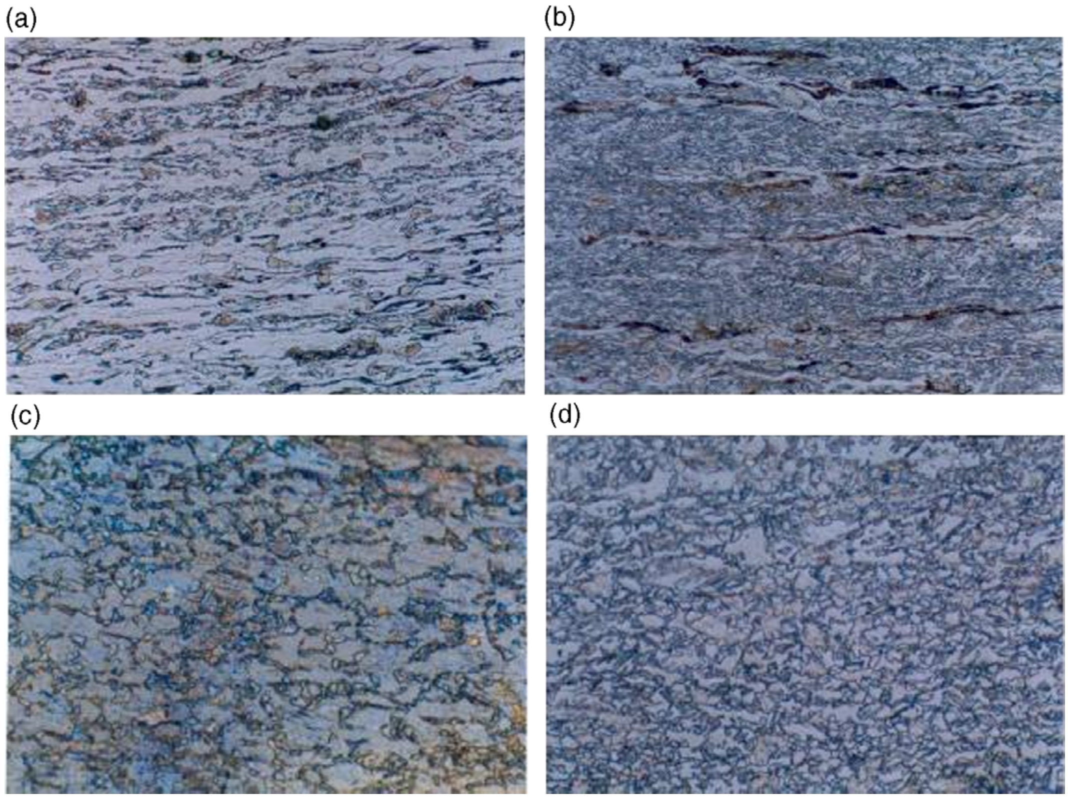

Fig. 1. (a and b) Cold rolled structures of the Si- and Al-TRIP steels. (c and d) Microstructures of the two steels after intercritical annealing 810 °C (Si-TRIP) and 860 °C (Al-TRIP), respectively.

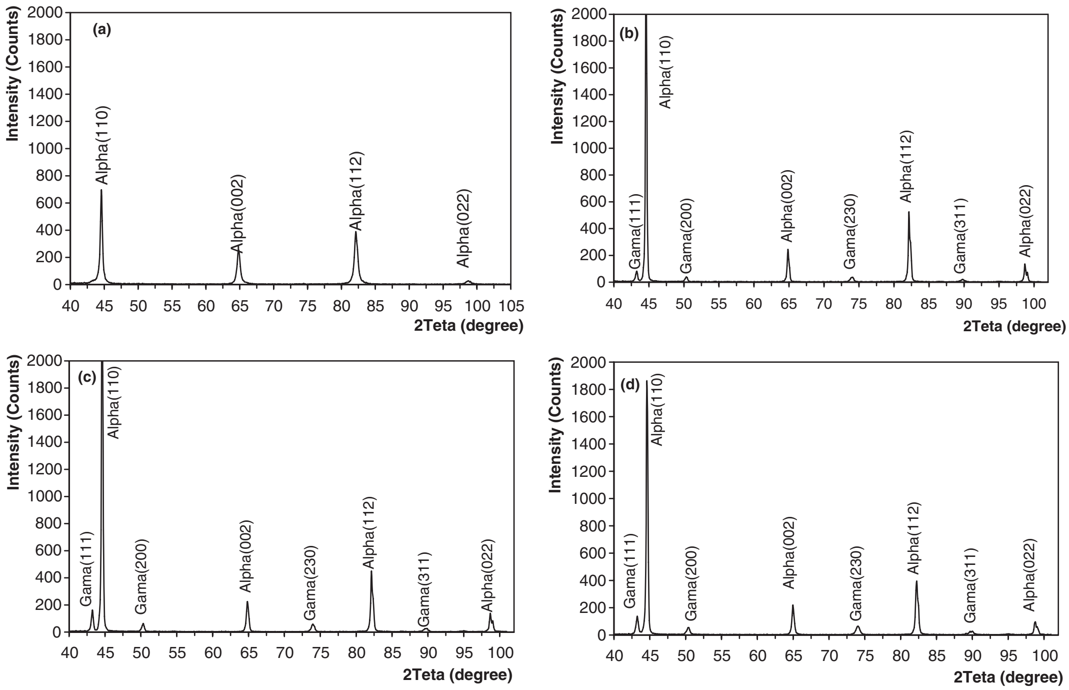

Fig. 2. XRD patterns of Al-TRIP samples, (a) cold rolled sheet and annealed at (b) 760 °C, (c) 810 °C and (d) 860 °C.

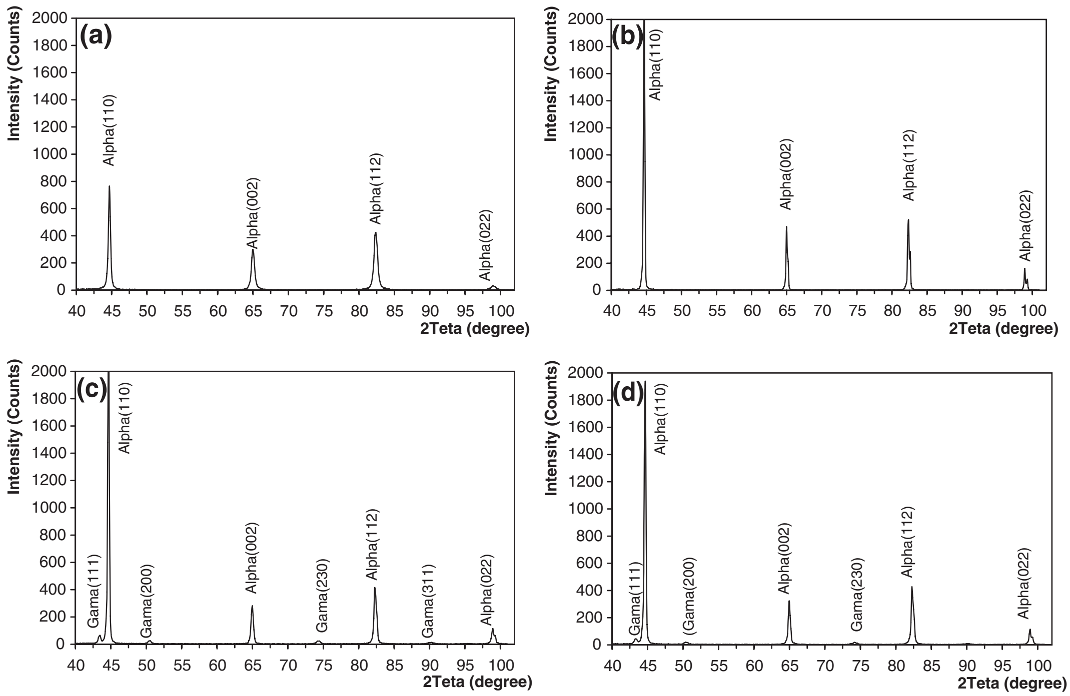

Fig. 3. XRD patterns of Si-TRIP samples, (a) cold rolled sheet and annealed at (b) 760 °C, (c) 810 °C and (d) 860 °C.

Table 2
Different combinations of retained austenite and ferrite peaks for measurement of the volume fraction of retained austenite

Volume fraction of retained austenite code	Retained austenite and ferrite peaks
V2	$(211)_\alpha/(311)_{\gamma+}(220)\gamma$
V3	$(200)_{\alpha+}(211)_{\alpha+}(220)_\alpha/$ $(200)_{\gamma+}(220)_\gamma(311)_\gamma$
V4	$(110)_{\alpha+}(200)_{\alpha+}(211)_{\alpha+}(220)_\alpha/$ $(111)_{\gamma+}(200)_{\gamma+}(220)_\gamma(311)_\gamma$
Ave	(V2+V3+V4)/3

peaks, i.e. $(111)_\gamma$, $(200)_\gamma$, $(221)_\gamma$, and $(311)_\gamma$ can be observed. Similar results were found for other Al-TRIP and Si-TRIP samples, although for Si-TRIP steel sheets annealed at 760 °C, no intensive peaks of retained austenite appeared in the XRD analysis.

In some research, different combinations of textured retained austenite and ferrite peaks have been used to determine the volume fraction of the retained austenite, whereas in other research only specific austenite and ferrite peaks have been considered without considering the texture of the phases [17–21]. For example, $(211)_\alpha$, $(220)_\gamma$ and $(311)_\gamma$ peaks have been used for retained austenite determination [8,11,12]. Possible combinations of retained austenite and ferrite peaks have been documented in Table 2. Fig. 4 illustrates the average and measured volume fractions of retained austenite based on the various retained austenite and ferrite diffraction peaks described in Table 2.

For the Al-TRIP steel, the volume fraction of retained austenite increases with increasing intercritical annealing temperature. However, for the Si-TRIP steel, the amount of retained austenite increases and then decreases with increased annealing temperature. At high temperatures, higher amounts of the initial austenite phase lead to greater nucleation of bainite at the isothermal holding temperature [5,8,11]. Thus, at annealing temperatures near A_{c3}, it is expected that the amount of retained austenite–i.e., nontransformed austenite–is reduced. Conversely, at relatively low temperatures (near A_{c1}), the volume fraction of the retained austenite decreases due to the lower amount of austenite present at this temperature.

The optimum temperature for intercritical annealing has been reported by Chung as $(A_{c1}+A_{c3})/2+20$ °C [22]. In the current research, this formula predicts optimum temperatures of 860 °C and 810 °C for the Al-TRIP and Si-TRIP steels, respectively.

According to Fig. 4, at 810 °C for the Si-TRIP steel, a maximum value of retained austenite has been observed while for the Al-TRIP steel this occurs at approximately 860 °C. These are in good agreement with Chung's analysis for the optimum intercritical annealing temperatures.

Comparing the volume fractions of retained austenite in these two TRIP steels indicates that there is a significant difference in their behavior at these conditions (Figs. 4 and 5). Although Si is more effective than Al in austenite retention in TRIP-aided steels [23], the lower volume fraction of retained austenite for the Si-TRIP steel evaluated here reflects the carbon content of the two steels. The higher carbon in the Al-TRIP steel means that the austenite is more saturated than that of the Si-TRIP steel which has a lower carbon content. Consequently, the instability of the austenite is greater for the Al-TRIP steel, resulting in a higher volume fraction of retained austenite.

In order to check the measurement of retained austenite in the textured material, one sample of Si-TRIP which was annealed at 810 °C was analyzed by both Cu and Co X-ray excitation. Comparison of the measured values shows that these two types of X-ray

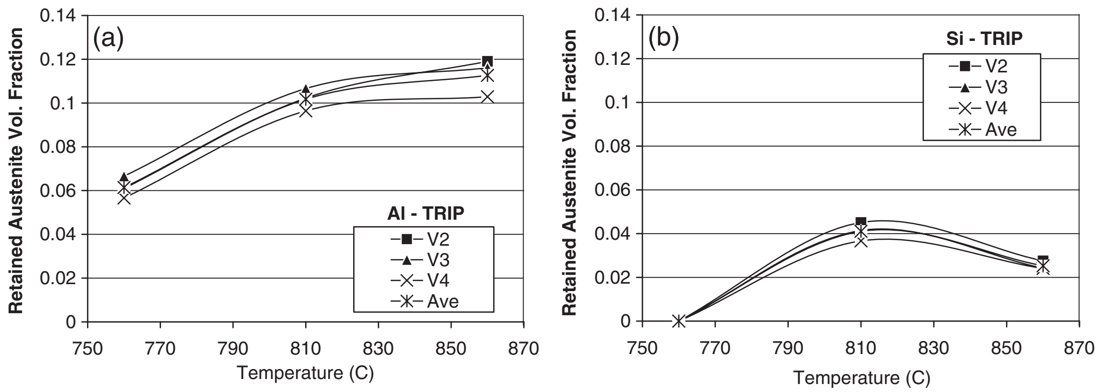

Fig. 4. Variation of the volume fraction of retained austenite with respect to intercritical annealing temperature for (a) Al-TRIP and (b) Si-TRIP.

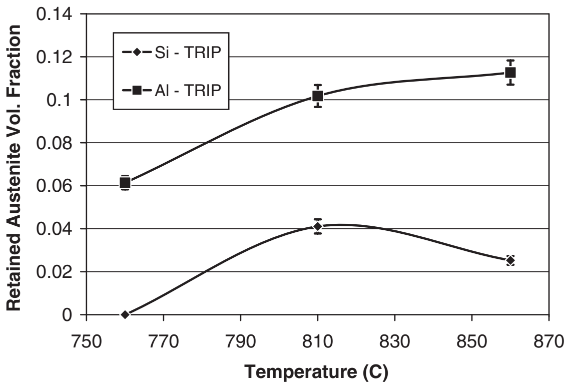

Fig. 5. Comparison of the volume fraction of retained austenite for Al- and Si-TRIP steels at different intercritical annealing temperatures.

radiation indicate slightly different amounts of retained austenite (Fig. 6). This could be due to the higher fluorescence of Cu radiation compared to Co in X-ray diffraction which results in a lower measured amount of retained austenite by the Cu radiation.

3.3. Carbon concentration in retained austenite

Carbon content of retained austenite is a major factor on the chemical stability of the retained austenite and, therefore, on the TRIP behavior. The carbon content of the retained austenite was calculated by the following equations [24]:

$$a\ (\text{Å}) = 3.580 + 0.0330C\ (\text{wt.\%}) \quad (1)$$

$$a\ (\text{Å}) = 3.585 + 0.0330C\ (\text{wt.\%}) \quad (2)$$

where a is the lattice parameter of the austenite as measured by the XRD results and C is weight percent of

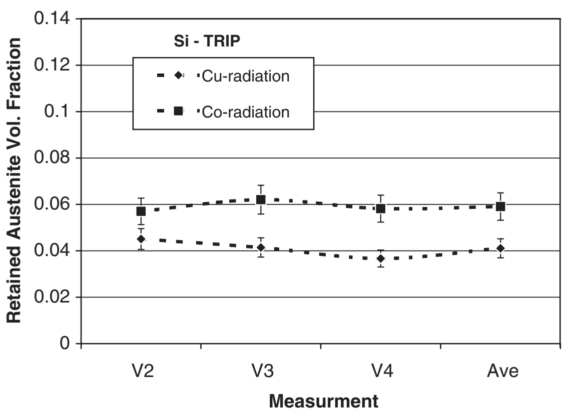

Fig. 6. Comparison of the measured volume fraction of retained austenite for annealed Si-TRIP sample at 810 °C based on XRD patterns of Cu-tube and Co-tube X-ray radiations.

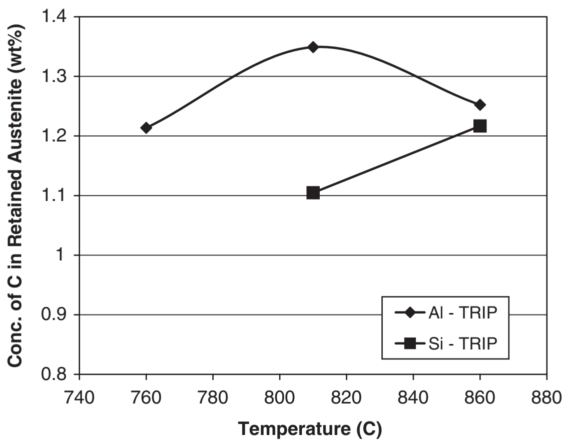

Fig. 7. Predicted carbon content of the retained austenite verses intercritical annealing temperature for Al- and Si-TRIP steels.

the carbon. Eqs. (1) and (2) were used to calculate the carbon concentration of the Si- and Al-TRIP steels, respectively. The calculated values at different intercritical annealing temperatures are shown in Fig. 7.

By retarding the transformation of austenite to bainite, the carbon content of the austenite increases and the volume fraction of retained austenite decreases. At higher intercritical annealing temperatures, an increase of the bainite phase leads to some decrease in the retention of austenite and the carbon content of the retained austenite increases significantly. The higher carbon content of the Al-TRIP steel compared with that of the Si-TRIP steel reflects the higher carbon content of the retained austenite in the Al-TRIP steel (Fig. 7).

4. Conclusions

In this research, the effect of intercritical annealing temperature on two types of TRIP-assisted steels was studied and the following were concluded:

1 -Al-TRIP steel with higher carbon compared Si-TRIP steel contains a higher volume fraction of retained austenite and, consequently, a higher carbon content in the retained austenite.
2 -The optimum intercritical annealing temperature in order to achieve the maximum amount of retained austenite is 860 °C for the Al-TRIP steel, whereas for the Si-TRIP steel it is 810 °C.
3 -An intercritical annealing of cold rolled TRIP-assisted steel sheet at a temperature of $(A_{c1}+A_{c3})/2$ +20 °C is the optimum condition for increasing the volume fraction of retained austenite.

4 -Estimated of retained austenite in textured TRIP steels based on different combinations of ferrite and austenite X-ray peaks provides reasonable results for the volume fraction of retained austenite.

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