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Comparison of deformation behavior of Al-TRIP and Si-TRIP steels

Yinghua Jiang[1, 2,*], Chunqian Xie[1, 2], Shuang Kuang[1, 2]

[1]Shougang Research Institute of Technology, Beijing 100043, China
[2]Beijing key Laboratory of Green Recyclable Process for Iron & steel Production Technology, Beijing 100043, China

*Corresponding author e-mail: yinghuajiang@163.com

Abstract. The research utilized TRIP steels with Al and Si compositions to understand the influence of Al and Si on austenite deformation behavior. Aluminum alloying increased the average C-content of retained austenite relative to Si-alloying. Aluminum alloying showed the higher mechanical stability of austenite and higher resistance to deformation induced martensite relative to Si-alloying.

1. Introduction

Retained austenite is desirable in AHSS because it increases ductility at a given strength level. In TRIP steels (first generation AHSS), retained austenite improves ductility through strain induced martensitic transformation that promotes work hardening and delays necking [1- 4].

TRIP steels rely on novel heat treatments to retain austenite. The TRIP steel is first intercritically annealed to establish a mixture of ferrite and C-rich austenite in microstructure. The TRIP steel is then rapidly cooled to the isothermal biotitic transformation (IBT) temperature. During the IBT step, biotitic ferrite forms at the expense of the austenite. Additionally, C is partitioned from the biotitic ferrite into the austenite, increasing the austenite C-content to promote the austenite stability [5, 6]. The carbide formation must be avoided during TRIP heat treatment, since carbides will dilute the austenite C-content. Carbide suppression in TRIP heat treatment is achieved by alloying with Si and/or Al. Both elements are insoluble in cementite and retard cementite formation [7, 8].

However, the influences of Si and Al alloying on deformation induced marten site formation during deformation are uncertain for both TRIP steels. The main goal of this research was to clarify the roles of Si and Al alloying on austenite stability and austenite deformation behavior during deformation.

2. Experimental procedure

To understand the influences of Al and Si alloying on austenite stability and austenite deformation behavior, the Al-TRIP and Si-TRIP steels are selected. The chemical compositions of the steels used for this research was provided in Table 1.

Experimental ingots made about 50kg in laboratory by vacuum induction furnace. They were homogenized at 1200°C for 1hours and then hot rolled to 3mm hot band. Finishing temperatures were kept above 870°C and coiling temperatures were kept at 670°C, then air cooled to ambient temperature. Then, the steel sheets are cold rolled to 1.2mm thick. In the present study, the Al-TRIP and Si-TRIP steels were produced using a laboratory annealing simulator. The heat treatment cycle fully simulated the industrial CAL and CGL. The heat treatment for the steels used for this research is shown in Table 2.

In order to distinguish each phase (ferrite, austenite etc.) the microstructure of steels were investigated after etching using Nita and Leper solution by optical microscope. To analyses the volume fractions and the average C contents in the retained austenite, X-ray diffraction (XRD) experiments were conducted with Cu-Kα radiation [9, 10]. In addition, transmission electron microscope (TEM) was performed to analysis phases in details. A few pre-set strain levels tensile tests were performed under the strain rate of 10-3/s. To calculate the T0 line, thermodynamic calculations were performed with Themocalc software.

Table 1. The chemical compositions of the steels used for the research (wt. %)

	C	Al	Si	MN	P	S
Al-TRIP steel	0.15	1.5	-	1.5	≤0.01	≤0.01
Si-TRIP steel	0.15	-	1.5	1.5	≤0.01	≤0.01

Table 2. The heat treatment compositions for the steels used for the research

		Annealing temperature(°C)	Isothermal holding temperature(°C)	Isothermal holding time(s)
#1	Al-TRIP steel	800	400	360
#2	Al-TRIP steel	800	460	60
#3	Si-TRIP steel	800	400	360
#4	Si-TRIP steel	800	460	60

3. Results and discussions

The optical microscopy (OM) microstructures of the Al-TRIP steel and Si-TRIP steel are shown in Fig. 1. The microstructures were observed to consist of polygonal ferrite and second phases such as kainite, marten site and retained austenite for two TRIP steels. The most retained austenite (blocky shaped) was located at grain boundaries; however, a small amount of isolated retained austenite were also observed in the grain interiors.

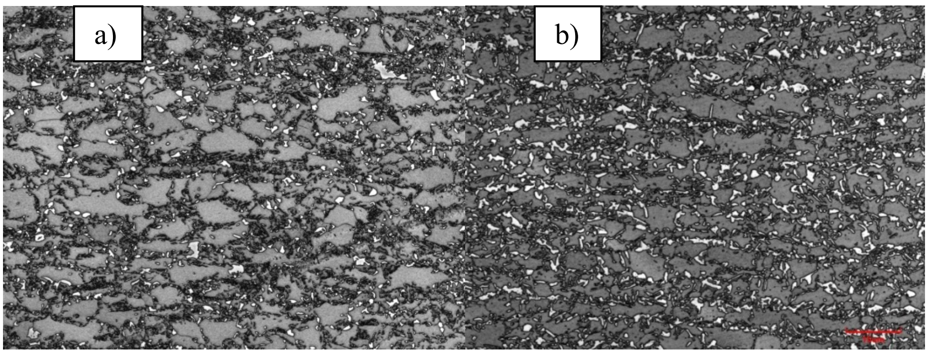

Figure 1. Optical micrographs of (a) Al-TRIP steel, (b) Si-TRIP steel

Fig. 2 shows the C content and volume fraction of retained austenite for Al-TRIP (#1, #2) steels and Si-TRIP (#3, #4) steels. From the XRD calculations, it was observed that the Al-TRIP steels have higher C content of retained austenite than Si-TRIP steels under the same condition. Thermo-calk calculations also indicated that Al addition moved the T0 line to right (Fig. 3), which implies that retained austenite in Al-TRIP steel is able to obtain a higher carbon content. This was borne out by our

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data as the Al-TRIP steel had higher C content of retained austenite compared with Si-TRIP steel. And it was observed that the Si-TRIP steels have higher volume fraction of retained austenite than Al-TRIP steels under the same condition.

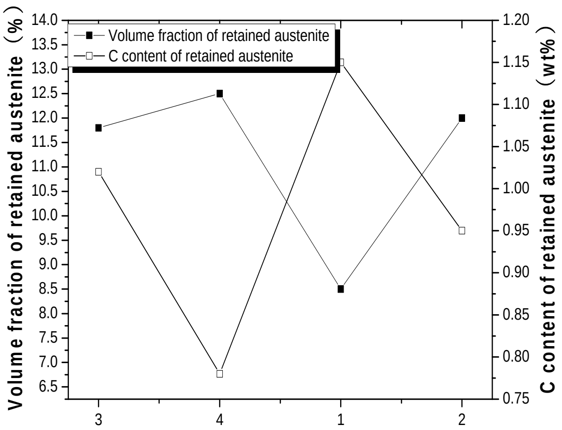

Figure 2. The C content and volume fraction of retained austenite for Al-TRIP (#1, #2) steels and Si-TRIP (#3, #4) steels

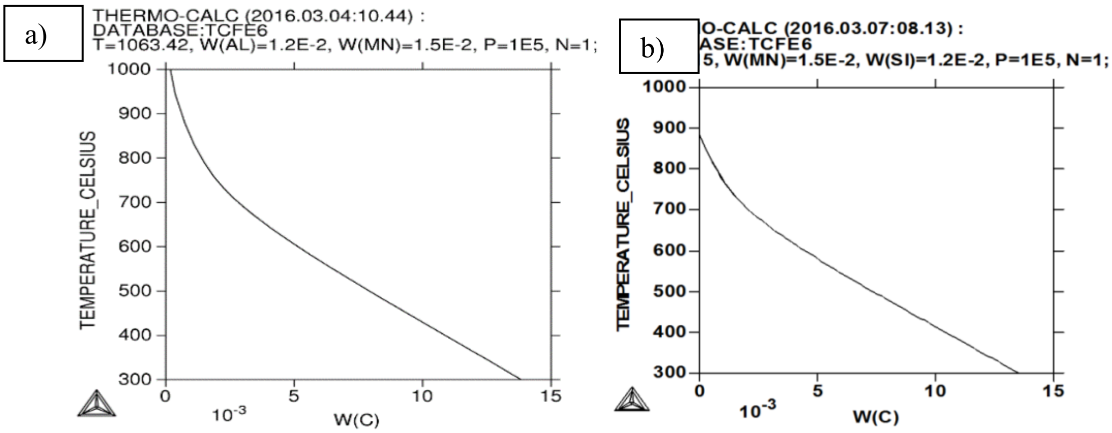

Figure 3. Calculated T0 line as function of C content. (a) Al-TRIP steel, (b) Si-TRIP steel

Fig. 4 shows that the volume fraction of retained austenite for Al-TRIP steel and Si-TRIP steel evolved as a function of strain. Compared with the Si-TRIP steels, the austenite in the Al- TRIP steel transforms gradually with deformation. Fig. 5 shows the dark field TEM micrographs of the Al-TRIP steel and Si-TRIP steel after tensile test. Fig. 5(a) and (b) show the untransformed retained austenite of Al-TRIP steel and marten site of Si-TRIP steel, respectively. A few austenites in Al-TRIP steel were not transformed even if fracture occurred. That is, Al-TRIP steel has a higher resistance to deformation induced marten site formation. This could be attributed to the fact that the austenite of Al-TRIP steel was more enriched in C.

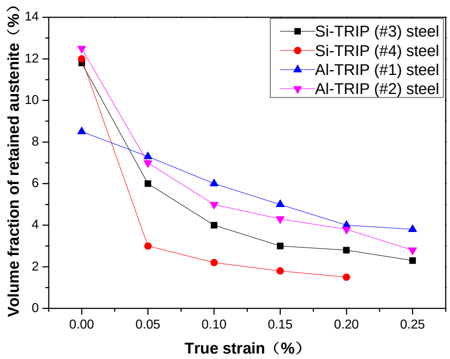

Figure 4. Volume fraction of retained austenite as a function of strain for Al-TRIP (#1, #2) steels and Si-TRIP (#3, #4) steels

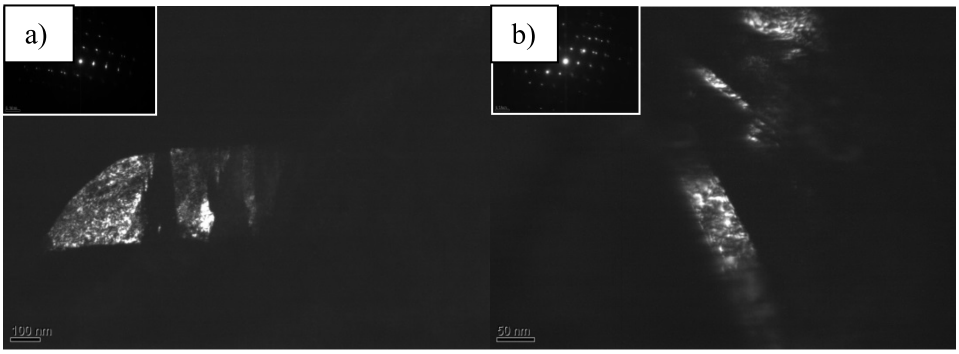

Figure 5. Dark field TEM micrographs of (a) untransformed retained austenite for Al-TRIP steel, (b) marten site for Si-TRIP steel

4. Conclusion

This work has demonstrated the effect of Al and Si on austenite deformation behavior. Compared with Si-TRIP steel, Al addition increased the average C content of retained austenite. Due to the reason compared to Si addition, Al addition has more stable austenite. Therefore, the austenite in Al alloying AHSS induced marten site transformation gradually with deformation.

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