Investigation of Transformation Induced Plasticity in High Al–low Si TRIP Steel

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Abstract

This study was conducted in order to investigate the influence of plastic deformation on the transformation of retained austenite in a TRIP steel with a high content of Al and a low content of Si. To the aim, appropriate treatments were used to produce the starting material (TRIP steel). The microstructure of the obtained steel was composed of bainite and phases including ferrite and retained austenite. Afterwards, 40 % plastic deformation was applied to the starting material using a rolling machine. Microhardness test, microstructural investigations and determination of volume fraction of retained austenite by x-ray diffraction method before and after 40% cold work demonstrated that the volume fraction of retained austenite in the starting material was decreased as the plastic deformation was increased. During the plastic deformation, large grains of retained austenite were transformed to martensite while the small ones tended to be stable.

Keywords: TRIP steel, Retained Austenite, Transformation.

1. Introduction

TRIP steels are low alloy steels in which the content of alloying elements does not exceed more than 3.5 %. These steels experience the mechanical transformation of austenite to martensite at ambient temperature, if appropriate thermo mechanical processes are applied [1,2]. Good formability, high ultimate tensile strength and absorbance of much energy during the plastic deformation are characteristics of these steels, making the use of low in thickness steel sheets possible in automotive industry. Consequently, there is a reduction in fuel consumption and air contamination [1,3,4].

The strain in which retained austenite transforms to martensite is controlled by carbon content and the grain size of the retained austenite [2,5]. The chemical free transformation energy of the retained austenite to martensite ($\Delta G^{\gamma \to \alpha'}$) decreases as the temperature increases and subsequently, the excessive mechanical driving force (U') increases. In temperatures more than M_s^σ, the required stress applied for martensitic transformation is higher than the yielding strength of austenite. Therefore, transformation does not occur until after a small amount of plastic deformation is applied to the austenite [2]. Silicon concentration in TRIP steels has a significant influence on the retained austenite

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extent, but the higher content(more than 0.5%) makes the galvanization process difficult. Adding Al instead of Si not only impedes the formation of carbide phases and increases the stability of retained austenite (Similar to silicon performance), but also improves the surface condition and subsequent galvanization process [6,7].

In spite of good mechanical behavior, TRIP steels are poor in galvanization. This is related to the chemical composition which contains Si. The objective of this study is to examine the mechanical behavior and properties of these types of steel with increasing the Al content and decreasing the Si content.

2. Experimental

Argon induction furnace was used to produce the investigated TRIP steel (Table 1). Ingot with dimensions of 50mm×100mm×300mm was homogenized at 1200°C for 2 hr. Afterwards, hot rolling was applied to decrease the thickness of the ingot down to 4 mm, and then pickled in Hcl and cold rolled down to 1 mm in thickness. In order to achive a typical microstructure of TRIP steel, the cold rolled sheet was heat treated in two-step by two salt bathes. strips were intercritically annealed at 825 °C for 120 s, and then immediately moved to another salt bath with 465 °C temperature and held 60 s for bainitic transformation (St.1). In order to examine the effect of transformation induced plasticity (TRIP phenomenon) on the heat trated sheets further, 40% Plastic deformation was applied at ambient temperature using a rolling machine (St.2). Figure 1 shows the schematic of the conducted process on the steel sheets.

Table 1. Experimental TRIP steel compositions

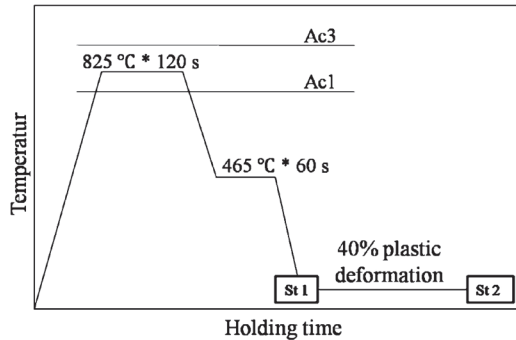| Element	C	Mn	Si	Al	Cr	S	P
Composition (wt.%)	0.22	1.48	0.59	0.83	0.1	0.009	0.003

Fig. 1. A schematic of the operations carried out on the test sheets.

For optical microstructure inspection, the heat treated sheets were polished and then etched in two stages, first with 10% aqueous sodium metabisulfite solution (4 gr dry sodium metabisulfite in 100 ml distilled water) and then, with 2% nital. In order to examine the microstructure with SEM, the second etchant was used and also, to determine the volume fraction of the retained austenite according to the ASTM E975, X-ray diffraction was used [8]. Volume fraction of the retained austenite was determined using both the intensity of the $(200)_\alpha$, $(211)_\alpha$, $(220)_\gamma$, $(311)_\gamma$ peaks and the following relation.

$$V_\gamma = \frac{\frac{1}{q}\sum_{j=1}^{q} I_{\gamma j}/R_{\gamma j}}{\frac{1}{p}\sum_{i=1}^{p} I_{\alpha i}/R_{\alpha i} + \frac{1}{q}\sum_{j=1}^{q} I_{\gamma j}/R_{\gamma j}} \quad (1)$$

P and q are the number diffracted peaks from ferrite and austenite phases, respectively. R value was calculated for ferrite and austenite using the reference [9].

In order to determine mechanical properties, tensile test according to ASTM E8 standard with the strain rate of 1 mm/min was conducted on all samples and then, microhardness test was conducted on different parts of fractured samples obtained from the tensile test.

3. Results and discussion

After inter-critical annealing of steel at 825 °C and subsequent cooling down to the bainite formation temperature (465 °C) and holding it for about 60 second at this temperature, carbon diffusion into the austenite occurred due to the transformation of austenite to the bainite and consequently, the stability of the austenite against transformation to the martensite was increased at high cooling rates. As a result, austenite phase remained as the white area in the microstructure. Therefore, the microstructure of the TRIP steel was composed of bainite (B) and different phases including

ferrite (F), the retained austenite (R_A) and probably, a little martensitel (Figure 2).

Figure 3 shows the microstructures of the TRIP steel before and after 40% plastic deformation as obtained from OM (optical microscopy). As shown, the retained austenite extent or white area decreased after plastic deformation. Furthermore, large grains of the remained austenite were not visible after plastic deformation (Figure 3(b)); this was due to the applied mechanical energy on such large grains which led to martensite transformation. But small grains of the remained austenite still existed in the microstructure because of their high stability.
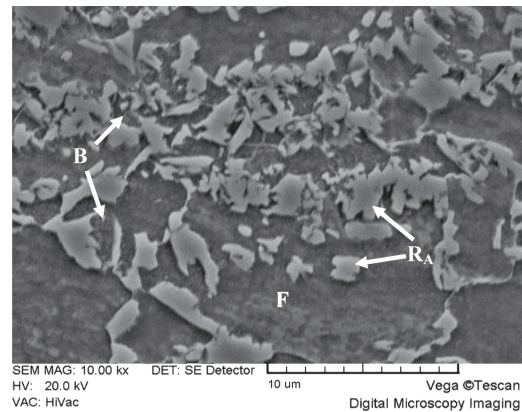

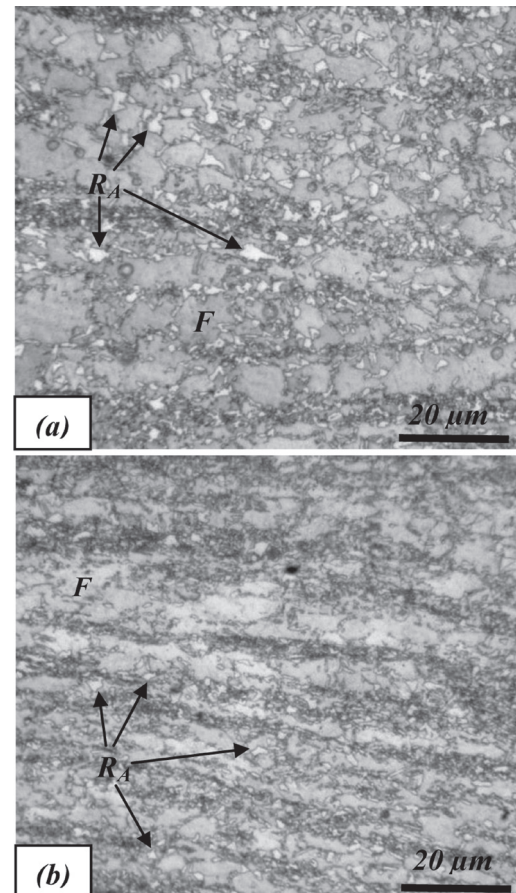Fig. 2. SEM micrograph of the investigated TRIP steel.

Fig. 3. Microstructure of TRIP steels (a) before and (b) after 40 % plastic deformation.

Results obtained from XRD test to determine volume fraction of the remained austenite before and after 40% plastic deformation are shown in Figure 4 and Table 2. According to Table 2, volume fraction of the retained austenite TRIP steel was decreased significantly by applying the plastic deformation. This reduction was due to the transformation of austenite to martensite under the external load at ambient temperature. In the presence of external mechanical energy at ambient temperture, driving force was available to accomplish the austenite transformation to the martensite. In TRIP steels, depending on the grains size of austenite phase and carbon content in austenite during plastic deformation, the retained austenite is transformed into martensite. The presence of 3.7% retained austenite in the microstructure after 40 % plastic deformation indicated that there was a small amount of retained austenite in the microstructure. According to Figure 3, the retained austenite had small grains and was stable toward the martensitic transformation with this amount of external mechanical energy.
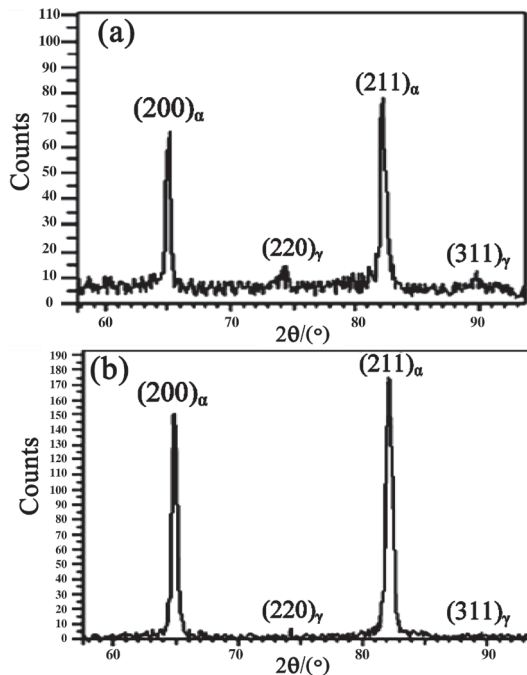

Fig. 4. XRD pattern of TRIP steel (a) before and (b) after 40 % plastic deformation.

Figure 5 displays the engineering stress-strain curve for TRIP steel before and after plastic deformation. Gradual transformation of the retained austenite to the martensite due to the increase of plastic strain caused the distribution of secondary hard phase in soft ferrite which resulted in the high ductility and toughness of ferrite. But in the case of 40% plastic deformed TRIP steel, the reduction of austenite phase due to the transformation of austenite to martensite under mechanical load and work hardening of ferrite significantly decreased toughness and ductility.
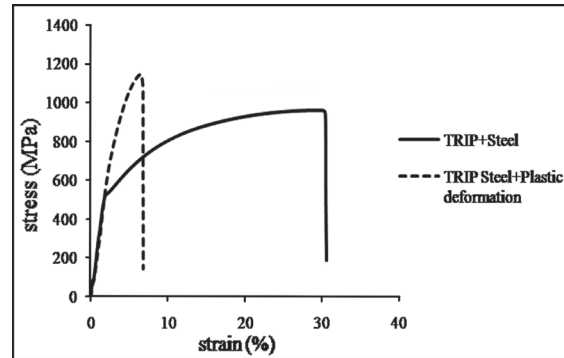

Fig. 5. Tensile engineering stress-strain curves of TRIP specimens before and after plastic deformation.

Figure 6 shows the results of hardness test on the samples of tensile test after fracture. The test was conducted on both 40 % plastic deformed and none deformed TRIP steels. This figure indicates that the hardness value of TRIP steel after 40 % plastic deformation was higher than that of before plastic deformation; however, the escalation rate of hardness near the fracture in the sample without prior plastic deformation increased much more than the one with 40% plastic deformed sample did. This behavior can be related to the volume fraction of the retained austenite before applying the tensile test (16.7%) in the microstructure of the TRIP steel without plastic deformation, which is higher than that of cold worked sample (3.7%). During the tensile test, the retained austenite was gradually transformed to the martensite which led to hardness increase in different parts of the sample. But for the small grains and the high content

Table 2. The results obtained from the XRD pattern

sample	2θ	(hkl)	d_{hkl}(Å)	R_{hkl}	Intensity	γ_{RA}
TRIP steel	74.5	$(220)_\gamma$	1.27	62.5	14	16.7%
	89.8	$(311)_\gamma$	1.09	70.61	12	
	65	$(200)_\alpha$	1.43	55.74	65	
	82.2	$(211)_\alpha$	1.17	103	78	
TRIP steel+ cold rolling	74.3	$(220)_\gamma$	1.27	62.47	7	3.7%
	89.6	$(311)_\gamma$	1.09	70.37	4	
	64.87	$(200)_\alpha$	1.43	55.64	149	
	82.1	$(211)_\alpha$	1.17	102.14	176	

of carbon, there should be applied much more plastic deformation in order to transform them to martensite. The mentioned condition occurred in the vicinity of the necked region (fractured place). Gradual transition of the retained austenite to martensite in the sample without prior cold work increased the hardness value by approaching the fracture. But in the sample with prior cold work (40% plastic deformation), there was a slight increase of hardness by approaching the fracture.
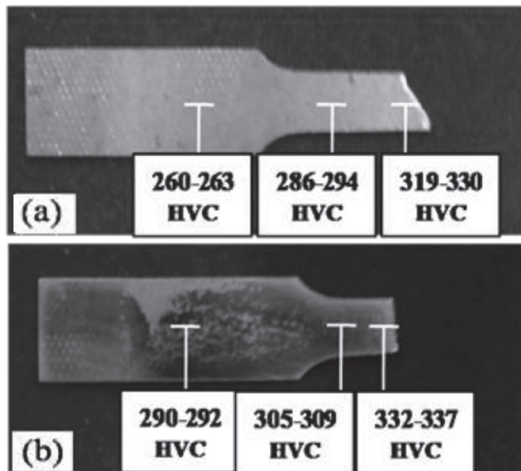

Fig. 6. Hardness distribution after fracture occurred on the tensile samples; (a) before and (b) after 40 % plastic deformation.

4. Conclusion

1. With applying the 40% cold work by rolling machine on TRIP steel, large grains retained austenite was transformed to the martensite. But the small grains of retained austenite were stable towards the transition.
2. Martensite formation from retained austenite happened gradually and increased by increasing the plastic deformation.
3. High volume fraction of retained austenite in the microstructure of steel caused the higher formation of martensite.

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