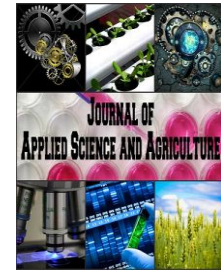




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Mechanical Properties in Fe-Mn-Si-C Transformation-Induced Plasticity Steel

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ABSTRACT

The microstructural changes and the tensile properties of TRIP-assisted steels resulting from different chemical compositions were investigated by using SEM, TEM, XRD and UTM. As a result of microscopic observation, the morphology of retained austenite could be characterized by two types: a granular type in steel containing higher Si and a film type in steel having higher C. In the case of the steel containing higher C with a tensile strength of 860 MPa and a total elongation of 38%, the film type retained austenite could be observed among the lath bainitic ferrites. Actually, the metastable retained austenite was required for good formability, which means that the chemical composition plays a significant role in the microstructure and tensile property of TRIP-assisted steel. With respect to the tensile property, each steel type that contained a suitable amount of Si and Mn demonstrated a typical TRIP effect on a stress-strain curve while steel that contained a higher Mn content exhibited similar behaviors, as demonstrated in the dual phase steels.

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INTRODUCTION

TRIP(Transformation Induced Plasticity)-assisted multiphase steel with Fe-Mn-Si-C (Zackay, V.F., 1967; Sakuma, Y., 1991; Krauss, G., 1989) as the basic chemical component is obtained through isothermal treatment in the temperature range for a bainite transformation after a process of intercritical annealing (in the region of ferrite and austenite) that is used to produce the dual phase steels. In fact, intercritical annealing and isothermal treatment has been used as a significant two-stage heat treatment for manufacturing TRIP-assisted steel. Some austenite is transformed into bainite during the process of isothermal treatment and suitable amounts of retained austenite are metastable at room temperature. In general, the TRIP-assisted steel shows the triple-phase microstructure composed of ferrite, bainite and retained austenite after an isothermal treatment. The retained austenite of TRIP-assisted steels transforms into martensite through mechanical deformation during the tensile test, and as a result, quite excellent elongation is obtained. This process has been termed, TRIP (Transformation Induced Plasticity). Since the retained austenite greatly influences the TRIP mechanism, current

research focuses on the volume fraction and stability of retained austenite. A combination of strength-elongation with TRIP assisted steel raises it above the level of high-strength steels that are applied in the automobile industry. The TRIP-assisted multiphase steel can be conducive to automobile safety due to mechanical properties such as high strength and expansive elongation, which means that it can certainly absorb the impact energy at the time of an automobile crash. More importantly, it is now being used for application in impact-absorbing steels with high levels of toughness (Matsumura, O., 1987; Liu, S.K. and J. Zhang, 1990). In this study, the effects of chemical composition (C, Si, Mn) on the microstructures and the tensile properties of three kinds of TRIP-assisted steels during the process of intercritical annealing and isothermal treatment were investigated. In particular, the morphology of retained austenite was analyzed by metallography over the three kinds of steels with different chemical compositions. Then, the volume fraction of retained austenite after an isothermal treatment was compared for each sample at room temperature. In addition, the changes on the stress-strain curve after a tensile test were examined relative to the chemical

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compositions (C, Si, Mn) in the TRIP-assisted multiphase steel.

1. Experiment procedure:

On the basis of Fe-Mn-Si-C, three kinds of TRIP-assisted alloys with different chemical compositions (C, Si and Mn) were designed and those alloys were melted in a VIM (Vacuum Induced Melting Furnace). The chemical compositions of the steels used in this study are shown in Table 1. For the case of HS steel, the composition of Fe-0.15C-1.37Si-1.93Mn was used as a standard sample, as this is a typical chemical composition of low carbon

TRIP-assisted steel. For the case of HC, the content of C was increased to 0.27%. In addition, for HM, the content of Si was decreased to 0.86% for the production of the alloy.

The alloy ingots were homogenized and maintained for approximately 12 hours at 1,250 °C. Then, the hot rolling was performed while maintaining the finishing temperature at 900 °C to produce hot-rolled steel sheets with a final thickness of 1.5 mm. Next, the annealing treatment was processed at the single region of austenite at 900 °C for 5 min.

Table 1: Chemical compositions of steels used in this study. (wt.%).

	C	Si	Mn	Fe
HS	0.15	1.37	1.93	Bal.
HC	0.27	1.38	1.88	Bal.
HM	0.16	0.86	1.82	Bal.

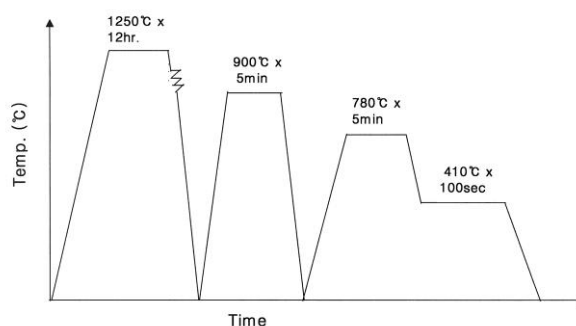


Fig. 1: Schematic diagram showing heat treatment in TRIP-assisted steel.

An X-ray diffraction test was performed to compare the volume fractions of retained steel austenite with different chemical compositions. X-ray diffraction analysis was processed in the range of $2\theta = 60^\circ \sim 90^\circ$ at a scanning speed of $2^\circ/\text{min}$. by use of a $\text{CuK}\alpha$ characteristic X-ray.

A tensile test was performed at a strain rate of 1 mm/min at room temperature to compare the tensile characteristics by chemical composition after a two-stage heat treatment. The specimens for a tensile test were made in a plate-shape, 6.0 mm wide, 40 mm long in the marked distance. In this case, the direction of the tensile axis was parallel to the rolling direction.

Figure 2 shows the scanning electron microscopies of the HS, HC and HM steels in which the intercritical annealing and the isothermal treatment were processed. A typical multiphase structure with a ferrite matrix, including 'the secondary phase' (namely, bainite and retained austenite) was shown. The morphology and volume fraction of the secondary phase were examined individually for each chemical composition in the steels discussed in this study. Actually, it was not easy to distinguish very fine retained austenite from bainite within the secondary phase (namely, bainite and retained austenite) in a ferrite matrix in the HS, HC and HM steels, by using SEM. On the other hand, the morphology of retained austenite in each

steel could be identified, by using TEM. For HS steels, the secondary phase was positioned at a multi-junction point along the granular boundary. Periodically, the granular type of retained austenite was observed. For the case of HC and HM steels, the volume fraction in the secondary phase increased more than that of HS. The bainite, transformed from the austenite in an isothermal treatment, was also observed with the retained austenite. In this case, using SEM, it was not easy to determine whether the morphology of retained austenite was of a granular or a film-type in the microstructure.

Periodically, the granular type of retained austenite was observed. For the case of HC and HM steels, the volume fraction in the secondary phase increased more than that of HS. The bainite, transformed from the austenite in an isothermal treatment, was also observed with the retained austenite. In this case, using SEM, it was not easy to determine whether the morphology of retained austenite was of a granular or a film-type in the microstructure. On the other hand, Figure 3 indicates the results of X-ray diffraction in the same scale along intensity on the HS, HC and HM steels. From all three steels, the retained austenite peaks, distinct from the ferrite peaks, can be observed. Fig 3(a) and 3(b) show X-ray diffraction peaks of the HS and HC steels, in which the Si and Mn contents are almost similar. There was no significant difference in the

(211) peak shape of the HS and HC steels. Figure 3(c) shows the X-ray diffraction peak of HM and the slight division at the peak end ($2\theta =$ around 82°) indicates the existence of martensite, which suggests that the retained austenite existed with unstable

martensite in the microstructure. This indicates that some quenched martensite formed at room temperature and existed simultaneously with retained austenite in the microstructure to result in a lower mechanical property of TRIP-assisted steel.

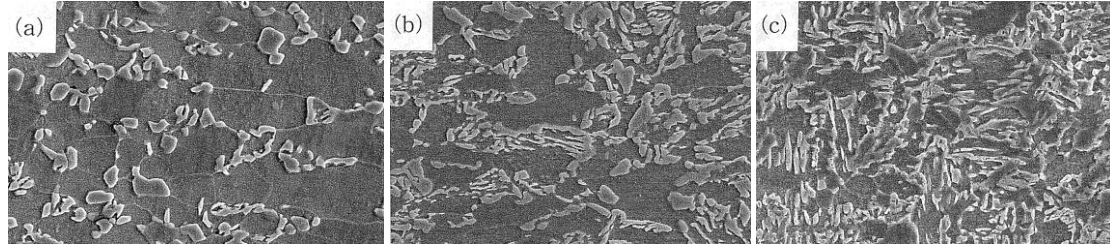


Fig. 2: SEM micrographs showing the microstructures in the secondary phase; (a) HS; (b) HC; (c) HM steels.

2. Comparison of Tensile Properties of Steels:

Figure 4 indicates the stress-strain curves from the tensile deformations of HS, HC and HM with different chemical compositions. From the above results, an analysis showed that the mechanical properties of steel are greatly affected by its chemical composition. Both HS and HC steels with a similar amount of Si and Mn contents showed a typical TRIP effect. In particular, for the case of HC with higher C content, 860 MPa of tensile strength and 38% of expansive elongation were obtained. A higher strength and a relatively lower elongation were obtained for the case of HM, in comparison with the other steels. This was due to the chemical

composition of this steel which contained relatively less Si than Mn (Jacques, P., 1997).

The fractured surfaces after rupture in HS, HC and HM were examined by using a scanning electron microscope, and the results are shown in Figure 5. Figure 5(a) shows a fractured structure in HS with ductile fractures. From this observation, it can be estimated that fractures have occurred in the process of formation and growth of dimples. Figure 5(b) indicates a fractured surface in HC, where much finer dimples were observed. This means that those dimples have added the high elongation capacity in HC. On the other hand, Figure 5(c) is a fractured structure in HM where several fractured surfaces with cleavages were examined.

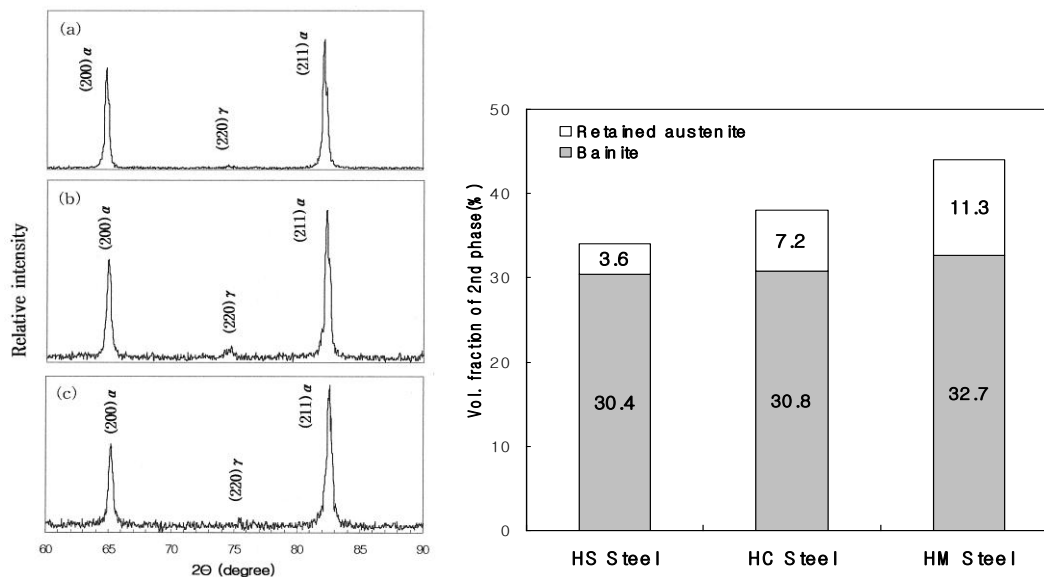


Fig. 3: Actual views of X-ray diffraction profiles of (a) HS, (b) HC and (c) HM steels(left) and The changes in the volume fraction in the 2nd phase of the HS, HC and HM steels.(right)

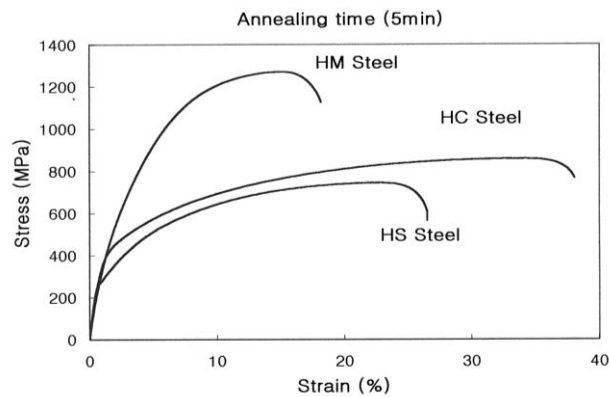


Fig. 4: Stress-strain curves of HS, HC, and HM steels discussed in this study.

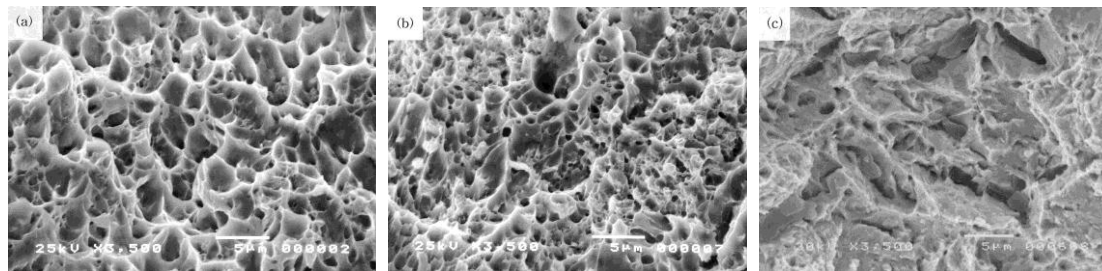


Fig. 5: Fractography showing the fractured surfaces after tensile testing: (a) HS; (b) HC; (c) HM steels.

3. Conclusion:

For the case of HC, with proper contents of Si and Mn, it has obtained a high strength of 860 MPa and an expansive elongation of 38%. For HM with less Si content than HC, a high tensile strength and a relatively low elongation were obtained, which means that the mechanical behaviors were similar to those in the dual phase steels. With respect to the volume fractions of retained austenite in the HS and HC steels, HC showed a higher volume fraction than HS when it was heat-treated in two stages after the annealing process at 900°C. For the case of HC, the film-type retained austenite existed in conjunction with lath bainitic ferrite in the multiple microstructures. For fractured structures after tensile test in HS, HC and HM, many cases of dimple structures were observed. The ductile fractures occurred mostly after plastic deformation in examining the fractured surfaces of the steels above.

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