Effect of Si content on thermal stability of austenite in low alloyed TRIP steel (Bainite transformation behavior in austemper of medium Si steel)

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The microstructures and tensile properties of Fe-0.2C-0.5/1.0/1.5Si-2.0Mn steel after austempering were investigated. Decomposition of austenite between bainite laths was observed after different austempering times. Austenite which decomposed faster is considered to have lower thermal stability. In austempering at 400℃ and 450℃, the thermal stability of austenite decreased as reducing Si content. In the 0.5Si steel, the thermal stability of austenite increased with the austempering temperature. And the thermal stability of austenite was almost the same in all steels after 500℃ austempering. These findings suggest that austenite can be stabilized even with lower Si content. Furthermore, the optimum austempering temperature to obtain more retained austenite could be higher in low Si steel.

Keywords: *Si content, thermal stability of austenite, TRIP steel, bainite transformation, austempering*

1. Introduction

Low alloyed TRIP (TRansformation Induced Plasticity) steel with high strength and ductility has been widely used in the automotive industry recently. Austempering heat treatment is utilized to produce low alloyed TRIP steel and it has mainly been discussed in high Si steels[1], since Si is considered beneficial for obtaining sufficient retained austenite. However, in galvanized steels, a high Si content causes poor galvanizability. Thus, establishment of the optimum austempering conditions for obtaining high ductility in low Si steel is demanded. At present, the effect of the Si content on transformation behaviors and thermal stability of austenite during austempering is unclear, especially in steels with lower Si content. In this study, the microstructures and tensile properties of Fe-0.2C-0.5/1.0/1.5Si-2.0Mn steel after austempering were investigated to clarify the effect of the Si content on transformation behavior and thermal stability of austenite during austempering.

2. Experiment

Alloys with different Si content were used in this study. Table 1 lists the chemical compositions with transformation temperature of the sample steels. A_3 temperatures were calculated by Thermo-Calc, and martensitic transformation start (M_s) temperatures were observed in dilatation tests.

The steels were melted in a vacuum furnace and cast into ingots, which were reheated at 1250°C and hot rolled to a thickness of 5.7mm. After hot rolling, the sheets were transferred to a furnace preheated to 490°C and slow cooled to room temperature to simulate the coil cooling process. The hot-rolled sheets were then ground and cold rolled to a thickness of 1.4mm.

Table 1 Chemical compositions and characteristic temperatures

Alloy	Composition(mass%)					Temperatures(℃)	
	C	Si	Mn	Al	N	A_3	M_s
0.5Si	0.2	0.52	2.0	0.023	0.0010	797	388
1.0Si	0.2	0.97	2.0	0.015	0.0011	813	377
1.5Si	0.2	1.49	2.0	0.014	0.0009	831	378

Figure 1 shows a schematic heat treatment pattern of salt bath. The cold rolled specimens were first austenitized at 900℃ for 600s and then rapidly cooled to an austempering temperature T_a of 400 ℃, 450 ℃ or 500 ℃ and isothermally held for various austempering times t_a from 0s to 3600s. After holding, the specimens were water quenched to room temperature.

The microstructures were observed by scanning electron microscope (SEM). The volume fraction of retained austenite (RA) was estimated by X-ray diffraction (XRD) with Mo–Kα radiation. The tensile tests were conducted with JIS13B test pieces (gauge length : 50mm, width : 12.5mm). The tensile direction was vertical to rolling direction.

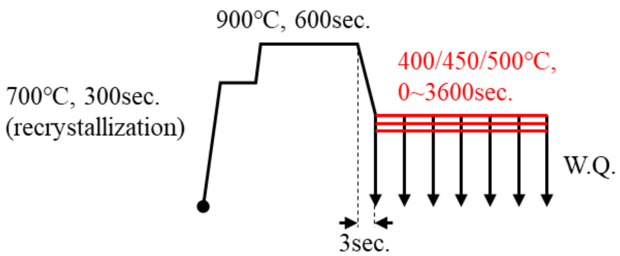

Figure 1 Schematic heat treatment pattern

3.Results and discussion

3.1 Phase diagram

Figure 2 shows the para-Acm and T_0, T_0' lines of all steels calculated by Thermo-Calc[2]. The para-Acm lines are austenite − (austenite + cementite) phase boundaries in para-equilibrium condition. The T_0 lines show the temperature and carbon concentration where austenite and ferrite of the same chemical composition have the same free energy. The T_0' lines are defined similarly but considering the stored energy (400J/mol)[3] of ferrite due to the displacive mechanism of transformation. Theoretical predictions showed that the T_0, T_0' lines do not change with Si content, and the para-Acm lines shift to the low carbon side with a decrease in the Si content.

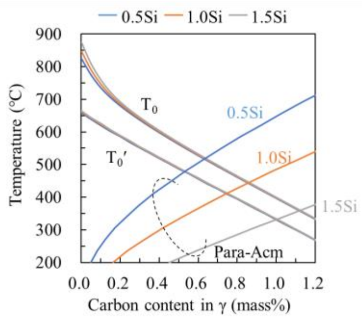

Figure 2 Para-Acm and T_0, T_0` curves calculated by Thermo-calc

3.2 Microstructure after austempering at 400℃

Decomposition of austenite between bainite laths was observed in all steels after different austempering times. Figure 3 shows the microstructures before and after austenite (γ) decomposition. Austenite decomposition was delayed as the Si content increased.

Figure 4 shows the relationship between the volume fraction of retained austenite V_{RA} and the austempering time t_a. The maximum V_{RA} increased with the Si content because austenite decomposition was delayed.

Austenite which decomposed faster is considered to have lower thermal stability. In austempering at 400℃, the thermal stability of austenite increased with the Si content. This might be due to the change in the carbon limit of para-Acm. In Figure 2, the para-Acm lines shift to the low carbon side as the Si content deceases. With bainite transformation processing, the C concentration in austenite easily exceeds the carbon limit of para-Acm easily in low Si steel, which is thought to be the reason for the decrease in the stability of austenite.

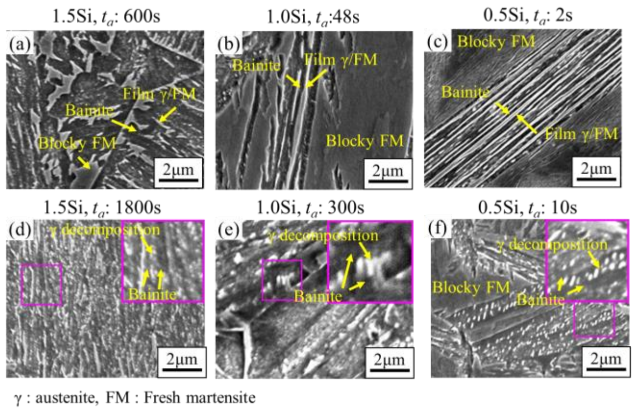

Figure 3 Microstructures before (a), (b), (c) and after (d), (e), (f) austenite decomposition

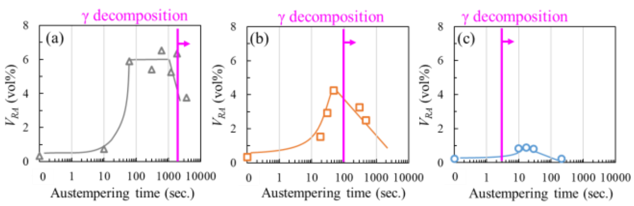

Figure 4 Relationship between V_{RA} and t_a, 1.5Si steel (a), 1.0Si steel (b), 0.5Si steel (c)

3.3 Microstructure of 0.5Si steel

Figure 5 shows the microstructures before and after austenite decomposition of the 0.5Si steel austempered at 400℃, 450℃ and 500℃. Austenite decomposition was delayed by increasing the austempering temperature. Figure 6 shows the relationship between V_{RA} and t_a. The maximum V_{RA} increased with austempering temperature since austenite decomposition was delayed.

These results indicate that the thermal stability of austenite increased with austempering temperature in the 0.5Si steel. A possible explanation is that the carbon limit of para-Acm increases with the austempering temperature. In Figure 2, the para-Acm lines show a locus from low temperature with a low C content to high temperature with a high C content. In the 0.5Si steel, the carbon limit of para-Acm increased with the austempering temperature and showed almost the same value as T_0 and T_0' after austempering at 500℃. As a result, the C concentration in austenite did not exceed the carbon limit of para-Acm until the end of bainite transformation, leading to higher stability of austenite.

Figure 7 shows the relationship between the maximum V_{RA} and the austempering temperature. The maximum V_{RA} was much lower in the 0.5Si steel after austempering at 400℃ and 450℃, and it was almost the same in all steels at 500℃ austempering. This indicates that the optimum austempering temperature could be higher in low Si steel.

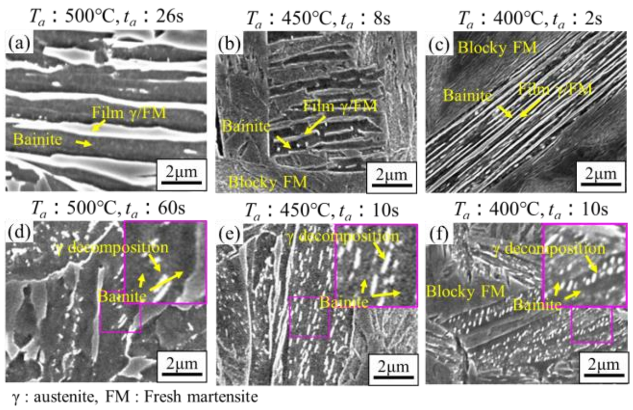

Figure 5 Microstructures before (a), (b), (c) and after (d), (e), (f) austenite decomposition

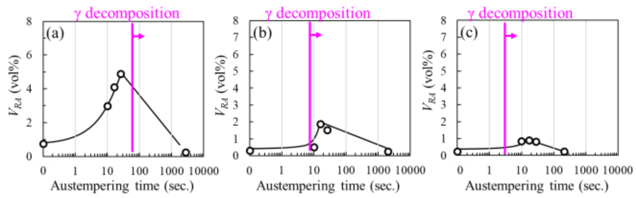

Figure 6 Relationship between V_{RA} and t_a, 500℃ austempering (a), 450℃ austempering (b), 400℃ austempering (c)

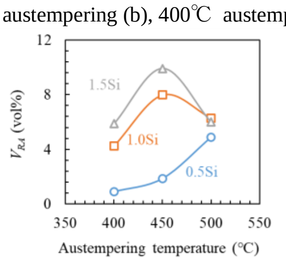

Figure 7 relationship between maximum V_{RA} and austempering temperature

3.4 Mechanical properties

Figure 8 shows the relationship between the tensile properties and austempering temperature. The tensile tests were conducted with the samples that achieved the highest V_{RA} at each austempering temperature. Tensile strength (TS) decreased as the austempering temperature increased. And the elongation (El) of the 0.5Si steel increased with the austempering temperature.

Figure 9 shows the relationship between the product of TS×El and V_{RA}. The product of TS×El increases with V_{RA}, which can be explained by the TRIP effect of RA.

Figure7, 8 and 9 suggest that the El of the 0.5Si steel increased with V_{RA} at higher austempering temperature due to an increase in the thermal stability of austenite.

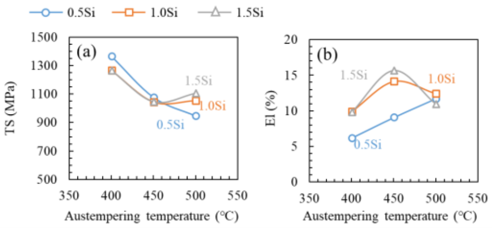

Figure 8 Relationship between tensile properties and austempering temperature

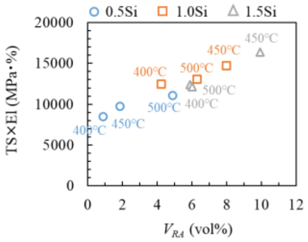

Figure 9 Relationship between tensile properties and austempering temperature

5.Conclusions

The microstructures and mechanical properties of Fe-0.2C-0.5/1.0/1.5Si-2.0Mn steel after austempering were investigated. The following conclusions were drawn.

・In the case of 400℃ austempering, the thermal stability of austenite increased with the Si content.

・In the 0.5Si steel the thermal stability of austenite increased with the austempering temperature.

・The thermal stability of austenite could be explained by para-Acm. If the carbon limit of para-Acm is much lower than those of T_0 and T_0', the C concentration in austenite can easily exceed the carbon limit of para-Acm with bainite transformation processing, leading to unstable austenite. On the other hand, if the carbon limit of para-Acm shows higher or almost the same value as T_0 and T_0', the C concentration in austenite cannot exceed the carbon limit of para-Acm until the end of bainite transformation, resulting in higher stability of autstenite. That is, the Si content influences the para-Acm lines and, as a result, influences the thermal stability of austenite.

・The El of the 0.5Si steel increased with V_{RA} when the austempering temperature was increased due to the increase in thermal stability of austenite.

These findings showed that austenite can be stabilized even with a lower Si content. Furthermore, the optimum austempering temperature could be higher in low Si steel in order to obtain more retained austenite.

References

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3) Bhadeshia HKDH: *Bainite in steels, theory and practice.* 3rd ed., (University of Cambridge and POSTECH, 2015)