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EFFECTS OF Nb AND Mo ADDTION ON MECHANICAL PROPERTIES OF HOT ROLLED TRIP-AIDED STEEL SHEETS

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Abstract

The development of high strength hot rolled TRIP sheet steels was carried out by taking into account the addition of Nb and Mo to 0.2C-1.5Si-1.5Mn mass% steel and coiling conditions after hot rolling. The results reveal that the addition of 0.05% Nb can attain higher elongation with high strength compared with Nb-free steel. The multiple addition of 0.2% Mo with 0.05% Nb results in higher TS (Tensile Strength) due to the large amount of fine NbMoC precipitates with more Nb contained in the steel without the deterioration of TS-El (Elongation) balance under hot roll conditions. The good ductility in 0.05% Nb-containing steel was mainly obtained by the large volume fraction and high carbon concentration of retained austenite. In addition, finely dispersed retained austenite made some contribution to the improvement in ductility.

Introduction

In order to meet the demand from the automobile industry for weight reduction while still taking into consideration possible hazards to the environment and safety improvements, the application of advanced high strength steel sheets such as TRIP (Transformation induced plasticity)-aided steel and DP (Dual Phase) steel have been examined. Automobile makers have asked for formable high strength steel sheets of 780 and 980 MPa tensile strength (TS) grade steels for suspension and structural parts.

It is well known that the higher the strength of steel sheets result in poorer press formability. Conventional HSLA (High Strength Low Alloyed) steels cannot satisfy the press formability for such high strength applications, especially for ultra high strengths such as 780 and 980 MPa TS grades. The TRIP effect is the most successful mechanism for increasing the strength of steels without deteriorating the strength and elongation balance. The formability of TRIP-aided steel primarily depends on the amount and stability of retained austenite. However, the steel sheets containing high carbon and high alloying elements such as Ni and Mn cannot be applied for automobile parts due to their poor weldability, low surface condition and high production cost. As a result, carbon content must be limited to less than 0.2% and Si, Mn and Al are limited to less than 2%, respectively. It is difficult to produce 780 or 980 MPa steel with such a chemical composition. However, although numerous research results on TRIP-aided steel produced by heat treatment after cold rolling have been reported [1], there were few reports on hot rolled TRIP-aided steel [2-7]. In addition, those that have been published were limited to relatively low strength levels. The microalloying elements such as Ti, Nb, V and Mo are known to increase strength through precipitation hardening. As many reports suggest the Nb or Nb and Mo addition to TRIP-aided steel resulted in higher strength and better ductility [6, 7]. The effect of those elements on TRIP- aided hot rolled steel was examined in this study.

Based on the above-mentioned background, the development of 780 MPa grade TRIP-aided steel was carried out by taking into account the addition of Nb and Mo and coiling conditions after hot rolling.

Experimental Procedure

Chemical compositions of steels and processing conditions

Five kinds of 0.2C-1.5Si-1.5Mn-0.005P-0.03Al (mass%) steels with different amounts of Nb and Mo were induction melted in air. The chemical compositions of steels are given in Table I.

Table I. Chemical composition of steels (mass%).

	C	Si	Mn	P	S	Al	Nb	Mo	N
A	0.21	1.49	1.45	0.005	0.003	0.032	-	-	0.0068
B	0.21	1.48	1.48	0.005	0.003	0.021	0.016	-	0.0061
C	0.21	1.49	1.49	0.005	0.002	0.028	0.017	0.10	0.0065
D	0.21	1.60	1.53	0.005	0.003	0.031	0.048	-	0.0073
E	0.20	1.47	1.51	0.004	0.003	0.028	0.047	0.20	0.0065

The rougher rolled 30 mm thick slabs to 3 mm in thickness. The reheating temperature and finishing temperature were 1200°C and 850°C respectively. The hot rolled sheets were water sprayed at 70°C/s to 750°C and air-cooled for 10 s and then water sprayed again to coiling temperature and held for 10 min, followed by air-cooling. In order to study the effect of coiling temperature, coiling temperatures were varied from 300 to 550°C with 50°C intervals.

Testing procedure

The specimens for the tensile test were cut in the longitudinal direction and machined to JIS No. 5 specimen with a thickness of 2.0 mm, whose gauge length and width were 50 mm and 25 mm respectively. The testing speed was 27 mm/min.

The volume fraction of retained austenite (γR) was measured by saturation magnetization measurement. The carbon concentration in retained austenite (Cγ mass%) was estimated by substituting the average lattice constant a_0 into the following equation, (1) [8]. The average lattice constant a_0 was determined by measuring the lattice constant of (200)γ, (220)γ and (311)γ by Mo-Kα radiation.

$$C\gamma=(a_0-3.578)/0.033 \tag{1}$$

The distribution of retained austenite was observed by FE/SEM-EBSP (Field Emission/Scanning Electron Microscope-Electron Back Scattering Pattern) with 150 nm step width. The analysis of EBSP was conducted by the OIM (Orientation Imaging Distribution) system.

Experimental Results and Discussion

Mechanical properties

The bainite transformation, which brings the carbon enrichment in retained austenite proceeds during the coiling process, in the case of hot rolled sheet. Therefore, the effect of coiling conditions is one of the most important process parameters in the hot rolling process to produce TRIP-aided steel.

The effects of alloying elements and coiling temperature (CT) on the tensile strength (TS) are shown in Figure 1. The TS decreases markedly with the increase in CT from 300 to 400°C in all of the steels and then a moderate decrease in TS with an increase in CT is observed except for high Nb-Mo steel E, which showed higher TS at CT of 450 and 500°C. The TS at a CT of 300 °C was approximately 1000 MPa in all of the steels. The TS of the steels coiled at temperatures higher than 400°C is sensitive to alloying elements. At a CT of 400°C, the TS of steel A is 760 MPa, whereas the TS of steels B and D is 820 MPa while Nb+Mo containing steels reach a TS of 880 MPa. The steels with 0.02 or 0.05% Nb show nearly the same TS over the entire CT range.

The effects of alloying elements and the CT on total elongation (El) are shown in Figure 2. Except for steel C which showed a peak El at a CT of 450°C, all of the steels show the highest El at a CT of 400°C. Steels D and E containing 0.05%Nb show a higher El than that of steel A coiled at 400°C, in spite of their higher TS. The highest El of 32% is obtained in steel D. In order to know the TS and El balance, TSxEl is calculated and shown in Figure 3. The results exhibit a similar trend as the El shown in Figure 2. The highest value is obtained at a CT of 400°C for steels D and E. Above all, steel A shows the lowest value.

Steels containing 0.05%Nb and 0.05%Nb+0.2%Mo show a high TSxEl value of 26000 MPa%, compared with other steels showing about 21000 MPa%. These results reveal that a Nb addition of 0.05% brings about a higher TS with better El, and the steel with 0.2% Mo together with 0.05% Nb shows a TSxEl as high as 0.05% Nb containing steel D, with a marked increase in TS.

The constituents of the total elongation (El) are the uniform elongation (U-El) and the local elongation. The behavior of the U-El is nearly same as that of the El, that is, all of the steels, except steel C, show the highest U-El at a CT of 400 °C. Steels D and E containing 0.05%Nb show a U-El higher than 20%. Steels B and C containing 0.02%Nb show the second best U-El, whereas steel A shows the lowest value of 16% at the peak CT of 400°C.

The n-value also shows nearly the same tendency as the El and U-El, though the CT showing highest value tends to shift to higher coiling temperatures, and attains a very low value for the low CT range. In spite of the higher TS in Nb containing steels (as compared to the Nb-free steel A), the n-value of steels D and E containing 0.05%Nb and steels B and C containing 0.02%Nb show a n-value as high as 0.25 and 0.20, respectively. On the other hand, steel A shows the lowest value being 0.16.

Retained austenite

The volume fraction and carbon concentration of retained austenite in the experiment of basic coiling conditions are shown in Figure 4. The behavior of retained austenite with CT and alloying elements is almost in accordance with the behavior of El and TSxEl shown in Figures 2 and 3. The volume fraction of retained austenite increases with an increase in the CT and shows its highest value at a CT of 400°C, and then decreases with increasing CT. In the high CT range of 500 to 550°C, Mo-added steels show a higher retained austenite content than other steels.

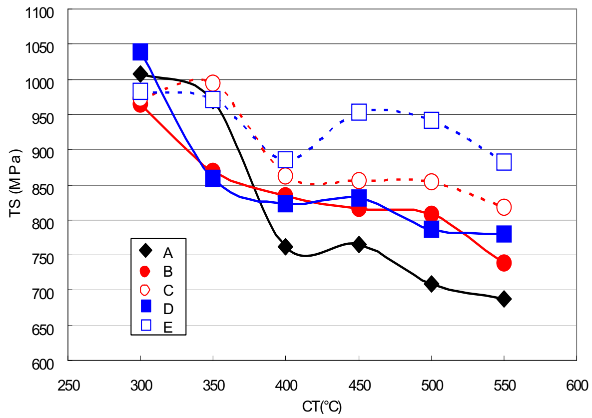

Figure 1. Effect of CT and alloying elements on TS.

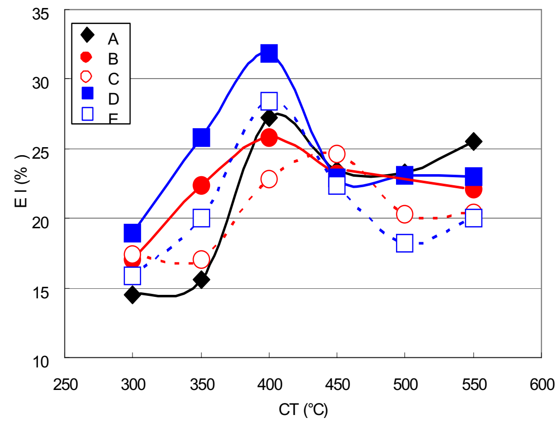

Figure 2. Effect of CT and alloying elements on El.

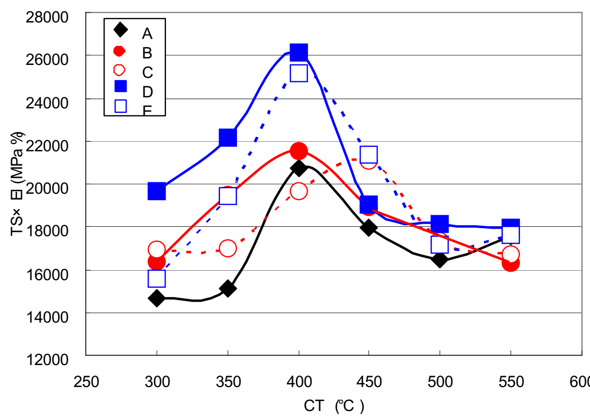

Figure 3. Effect of CT and alloying elements on TS and El balance expressed by TSxEl.

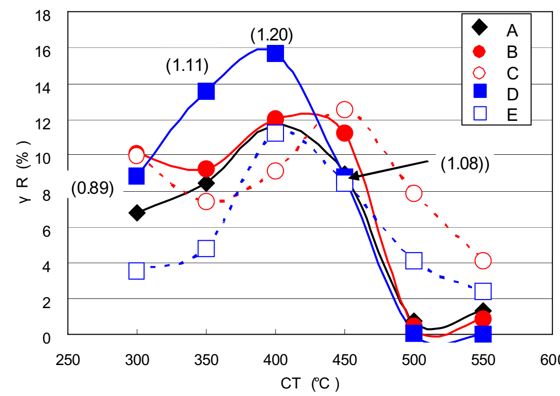

Figure 4. Effect of CT on volume fraction of retained austenite (γR) and carbon concentration in retained austenite of steel D expressed in parenthesis.

The volume fraction of retained austenite in steel D showing the highest El is as much as 16%. This value is about 4% higher than in other steels. Except for Mo added steels, the volume fraction of retained austenite at a CT higher than 500°C is almost 0%. The carbon concentration in the retained austenite of steel D also showed with 1.2% maximum value at a CT of 400°C.

Microstructure

The microstructure of steel A is composed of equiaxed ferrite and a second phase. On the other hand, the Nb containing steels show an elongated second phase. In order to understand the morphology and dispersion of retained austenite, observation by EBSP was carried out for steels A and D, of which the results are shown in Figure 5. The γ -phase is represented by white and the α -phase is represented by gray contrast. The black area has not been identified as either γ - or α -phase. These structures must be bainite. The results clearly show that the size of retained austenite in 0.05% Nb containing steel D is small and its dispersion is very fine. Most of the retained austenite in steel D exists along the bainitic ferrite lath. On the contrary, the size of retained austenite in Nb-free steel A is large and coarsely distributed. The retained austenite exists mainly along the ferrite boundary, but along the bainitic ferrite lath as in steel D.

The El of TRIP-aided steel is determined mainly by the volume fraction of austenite [2, 3] and the stability of retained austenite being mainly controlled by the carbon content in the retained austenite [12]. The change in volume fraction and carbon concentration of retained austenite with the CT shown in Figure 4 is almost in accordance with the behavior of the El. These results mean that the El is mainly determined by the volume fraction and carbon concentration of retained austenite. In addition, it is reported that the El of TRIP-aided steels is influenced by several factors such as the morphology of retained austenite [10-12], inter-particle spacing of retained austenite [13] and the morphology of the ferrite matrix [11, 12]. The morphology of retained austenite is strongly affected by the addition of Nb as shown in Figure 5.

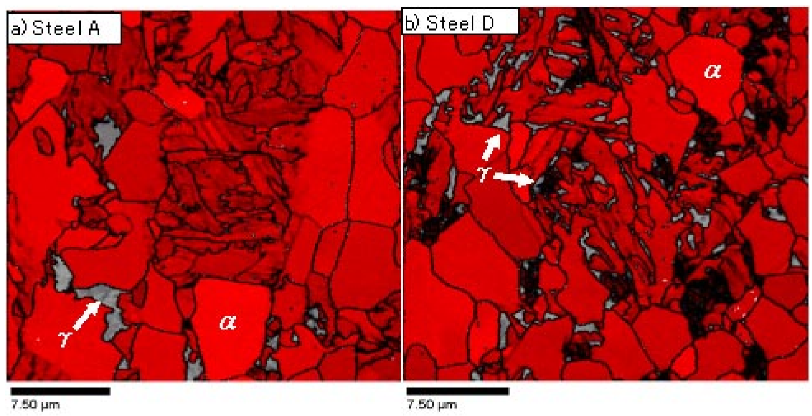

Figure 5. Effect of Nb addition on γ distribution observed by EBSP.
(γ -phase is indicated by white and α -phase is indicated by gray.)

In some work performed on multiphase steels, the very important role of microstructural refinement on formability is pointed out. Regsbee et al. [13] clearly showed a fine dispersion of retained austenite is advantageous in attaining a high rate of work hardening and high n-value, even when the amount of retained austenite is constant. Although it was difficult to measure the exact inter-particle spacing of retained austenite in this experiment, it is clear that smaller inter-particle spacing is obtained in steel D. This must cause the high rate of work hardening in steel D, according to the experimental result by Regsbee et al. [13] and Ashby's theory [14].

The fact that the finely dispersed retained austenite and better a El and n-value are obtained in 0.05% Nb steels, as compared to 0.02% Nb steels, demonstrates the importance of a Nb addition as high as 0.05%. Judging from the same TS between steels B and D, a considerable amount of the added Nb in 0.05% steel must be in solid solution. Not only NbC precipitates, but also the solid solute Nb efficiently brings about grain refinement and small inter-particle spacing.

In order to ascertain the austenite grain size, the steels were water-quenched from 750°C after the same hot rolling and cooling condition as in the other experiments. The obtained optical micrographs are shown in Figure 6. Steel A shows large and blocky martensite, on the other hand steel D shows a small and elongated morphology. In steel D, the observed ferrite formation is not only along the prior austenite grain boundary as in steel A, but also inside the deformation band.

The state of Nb in each stage of hot rolling in steel D was observed by chemical analysis. As shown in Figure 7, at the reheating stage at 1200°C about half of added Nb is precipitated. During hot rolling, about 20% of the Nb added is precipitated and 10% of it is precipitated during cooling and coiling after hot rolling. Even in the final product, about 20% of the Nb added was retained in solid solution. The difference in microstructure due to the addition of

0.05%Nb must be brought about by Nb in solid solution in 0.05% Nb containing steels, in addition to NbC precipitates through a small and elongated austenite microstructure.

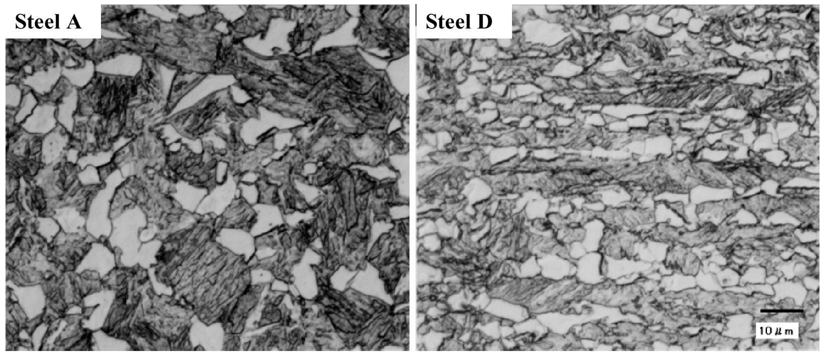

Figure 6. Effect of Nb on optical micrographs water quenched from 750℃.

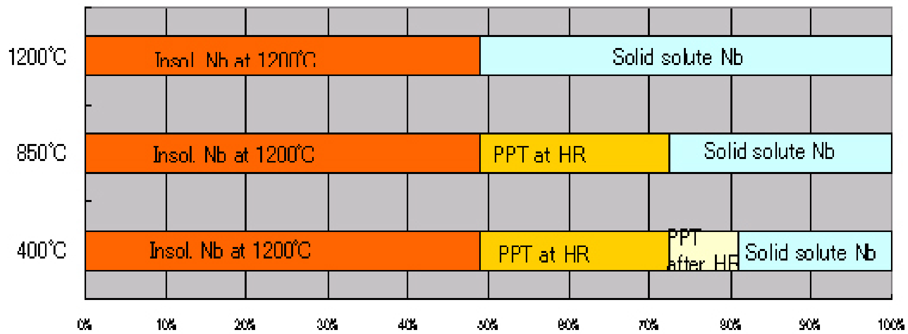

Figure 7. State of Nb in each stage of hot rolling process by chemical analysis.

<u>Experiment by heat treatment using cold rolled sheet</u>

The hot rolling experiments can not precisely clarify the effect of holding time at the coiling temperature due to the difficulty in controlling the holding temperature and time during coiling. Accordingly, the change in mechanical properties with the change in holding time at 400°C was investigated by heat treatment using cold rolled sheets of steels A, D and E. The heat cycle of this experiment is shown in Figure 8.

With increasing holding time at 400°C, the TS decreases and the YS and El increase. These values reach a stable point at around 300 s. This phenomenon must be explained by the decrease in the volume fraction of martensite with the increase in holding time from 30 s to 300 s. Steel D shows the highest El and TSxEl as obtained in hot rolled experiments. The volume fraction of retained austenite of 0.05% Nb containing steels is higher than that in Nb-free steel A. Steel D also shows a high TSxEl value even after a long holding time of 2000 s, i.e., about half an hour, corresponding to the actual holding time in the coiling process. This experiment supports the beneficial effect of Nb addition on the TS-El balance obtained by the hot rolling experiment.

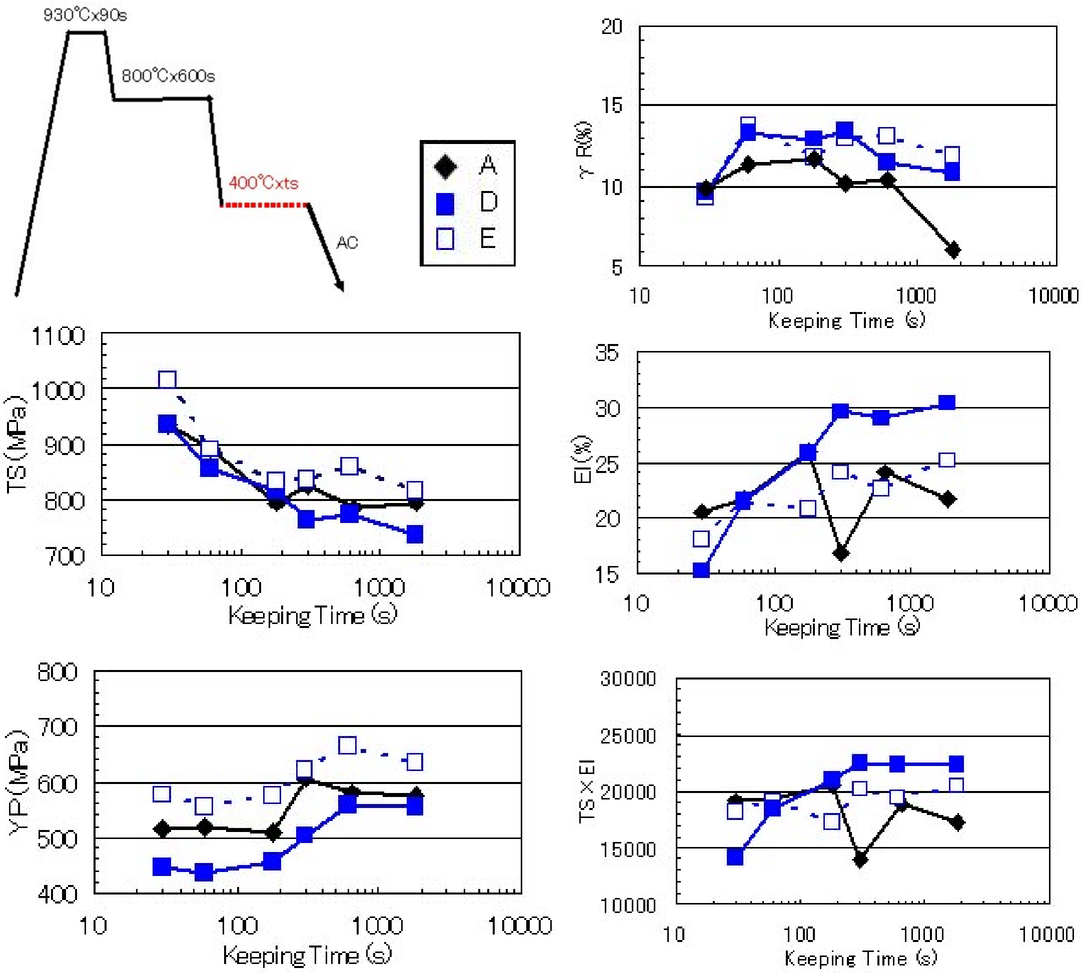

Figure 8. Effect of maintaining time at 400℃ on TS, YP, El, TS-El balance (TSxEl) and volume fraction of retained austenite (γR).

Summary

In order to develop a 780 MPa grade TRIP-aided hot-rolled steel sheet, the effects of Nb and Mo additions to 0.2%C-1.5%Si-1.5%Mn steel and the coiling conditions after hot rolling on the mechanical properties were investigated. The following conclusions could be drawn:

1. A 0.05%Nb containing steel showed a higher El than Nb-free steel, regardless of the higher TS. The obtained TS and El at the best coiling temperature of 400°C were 822 MPa and 32%. Since the TS and El in Nb-free steel under the same hot rolling condition were 762 MPa and 27%, respectively, it is clear that the addition of Nb is effective in producing 780 MPa grade hot rolled TRIP-aided steel with excellent El.

2. The multiple addition of 0.2% Mo with 0.05% Nb resulted in an about 120 MPa higher TS as compared to Nb-Mo-free steel. This result suggests that the addition of Mo with Nb is effective in producing a higher TS grade hot rolled TRIP-aided steel.

3. The highest El and TSxEl were obtained when the steels were coiled at 400°C. This condition corresponded to the condition showing the highest volume fraction and carbon concentration of retained austenite.

4. The beneficial effect of 0.05%Nb addition was confirmed by the heat treatment after annealing at 930°C. The 0.05%Nb containing steel kept the high TSxEl even at a holding time of 2000 s, which corresponds to the actual holding time in the coiling process.

5. The good ductility in the 0.05% Nb containing steel was mainly obtained by a large volume fraction and high carbon concentration of the retained austenite. In addition, finely dispersed retained austenite also contributed to an improvement of the ductility.

References

1. Proc. of "International Conference on TRIP-Aided High Strength Ferrous Alloys", ed. by De Cooman, B.C. Ghent, Belgian, (2002).
2. Tsukatani, I. Hashimoto, S., and Inoue, T.: ISIJ Int., 31 (1991), 992.
3. Kawano, O. Wakita, J. Esaka, K., and Abe, H.: Tetsu-to-Hagane, 82 (1996), 232.
4. Park,S. Han, H. Lee, J., and Lee, K.: Proc. of "40th MWSP Conf.", Pittsburgh, (1998), 283.
5. Tosal-Martinez, L. Vanderschueren, D. Jacobs, S., and Vandeputte, S.: Steel Res., 72 (2001), 412.
6. Takechi, H.: Proc. of "HSLA Steels '2000", Xi'an, China, (2000), 113.
7. Timokhina, I. Hodgson, P., and Pereloma, E.: Proc. of "International Conference on TRIP-Aided High Strength Ferrous Alloys", ed. by De Cooman, B.C. Ghent, Belgian, (2002), 153.
8. Ruhl, R.C., and Cohen, M.: Trans. AIME, 245, (1969), 241.
9. Sugimoto, K. Usui, N. Kobayashi, M. and Hashimoto, S.: ISIJ Int., 32 (1992), 1311.
10. Nagasaka, A. Sugimoto, K. Kobayashi, M. Kobayashi, Y., and Hashimoto, S.: Tetsu-to-Hagane, 85 (1999), 885.
11. Hashimoto, S. Kashima, T. Ikeda, S., and Sugimoto, K.: Tetsu-to-Hagane, 88 (2002), 400.
12. Sugimoto, K. Kanda, K. Kikuchi, R. Hashimoto, S. Kashima, T., and Ikeda, S.: ISIJ Int., 42 (2002), 910.
13. Regsbee, M., and Van der Arend, P.J.: Proc. of "Formable HSLA and Dual-Phase HSLA steels", ed. by Darvenport, A.T. AIME, New York, (1979), 56.
14. Ashby, M.F.: Philos. Mag., 14 (1966), 1157.