FRACTURE TOUGHNESS OF THE WELDED JOINT OF NEW GENERATION ULTRA-FINE WEATHERING STEEL

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ABSTRACT

New generation ultra-fine Al-Si weathering steels were developed at NIMS. Though Si and Al can increase the atmospheric corrosion resistance, they decrease the toughness of steels at the same time. The purpose of this work is to investigate the effects of Si and Al on weld bond toughness, and reveal the dependence of weld bond toughness on chemical composition for Al-Si steels.

In this work, the weld bond toughness was found to be mainly determined by the chemical composition of base metal, i.e., the equivalent carbon content (C_{eq}). However, within a certain range of C_{eq}, this correlation did not hold for the newly developed Al-Si steels, and weld bond toughness increased with carbon content. The weld bond toughness of Al-Si steels can be improved by increasing carbon content.

KEYWORDS

Charpy impact test, welded joint, toughness, weld bond, equivalent carbon content, weathering steel, grain refinement

INTRODUCTION

Because the exhausting of metal elements is advanced in the global scale, circulating of the natural resources is becoming more and more important. Ni, Cr, Mo, W, Cr elements are effective in increasing the atmospheric corrosion resistance, however, they are difficult to recycle. Because of this shortcoming and no ability to producing their elements in Japan, the utilization of these elements in weathering steel is hoped to be avoided. From the view point of recycling, new generation ultra-fine weathering steels were developed at NIMS, in which atmospheric corrosion resistance was obtained only by Si and Al elements [1,2].

Adding Si and Al can increase the atmospheric corrosion resistance and the strength of steels [2], but it decreased the fracture toughness. Though the decrease in toughness due to the addition of Si and Al has been solved by refining ferrite grain size for the base metal, the effects of Si and Al on the weld bond which is usually recognized as a most weak region in the welded joint was not well known. Therefore, ensuring enough weld bond toughness becomes critical for the practical utilization of the newly developed weathering steels, and also becomes the concern of this study.

In this work, Charpy impact tests were performed on simulated weld bond to evaluate the weld bond toughness of the developed Al-Si weathering steels. The effects of Al and Si on weld bond

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toughness were discussed, and the relationship between weld bond toughness and equivalent carbon content was investigated.

EXPERIMENTAL

Four Al-Si weathering steels, G1 ~ G4, were used for this work. For compensating the decrease in fracture toughness due to Al and Si, ferrite grains in G1 ~ G4 were refined. Two Si-Mn ultra-fine grained steels (0.15C and 0.10C steels) and commercial SM490C and HT780 steels were also used. Their chemical composition is listed in Table 1, in which C_{eq} and P_{cm} are the equivalent carbon content and cold-crack sensitivity, respectively. C_{eq} and P_{cm} are given by Eq. (1) and Eq. (2), respectively [3].

Table 1 Chemical composition (wt%)

No.	C	Mn	Si	Al	Cu	Ni	Cr	Mo	V	B	C_{eq}	P_{cm}
G1	0.1	1.5	0.6	0.6							0.35	0.2
G2	0.17	1.5	0.6	0.6							0.42	0.27
G3	0.1	1.5	0.8	0.8							0.35	0.2
G4	0.17	1.5	0.8	0.8							0.42	0.27
0.10C	0.1	1.43	0.31								0.34	0.18
0.15C	0.16	1.45	0.3								0.40	0.24
SM490C	0.16	1.5	0.27								0.41	0.24
HT780	0.11	0.84	0.2		0.23	0.78	0.48	0.43	0.028	0.0012	0.50	0.24

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Cu+Ni}{15} \tag{1}$$

$$P_{cm} = C + \frac{Si}{30} + \frac{Mn+Cu+Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B \tag{2}$$

where the element symbols represent the contents of the corresponding elements in weight percent. It is obvious that G1 and G3 have lower C_{eq} than SM490C, and the C_{eq} of G2, G4 and 0.15C steels is almost equal to that of SM490C.

Simulated weld bond, which was prepared by simulation technique, was used to substitute practical welded joint in this work. The maximum peak temperature of the simulating welding thermal cycle is 1350℃, and the cooling time from 800℃ to 500℃ is 8sec and 19sec, respectively.

The weld bond toughness was evaluated by Charpy impact test with V-notch full size (10mm×10mm×55mm) specimen. Charpy impact tests were performed from high temperature to low temperature to obtain full impact curve.

RESULTS AND DISCUSSION

Effects of Al and Si on microstructure

Al and Si are ferrite-forming elements. Their effects on microstructure can be reflected through equilibrium diagram. Figure 1 shows the phase equilibrium diagrams calculated with Thermocalc. The chemical composition (wt%) of Figs. 1(a), (b), (c) and (d) is, respectively, 1.5Mn-0si-0Al, 1.5Mn-0Si-0.8Al, 1.5Mn-0.8Si-0Al and 1.5Mn-0.8Si-0.8Al. When increasing Al content from 0%

to 0.8% ((a) → (b); (c) → (d)), γ phase region shifted to the high carbon content side, and α-γ two phase region enlarged. γ phase region shrank along the temperature axis and α-γ two-phase region also enlarged when increasing Si content from 0% to 0.8% ((a) → (c); (b) → (d)).

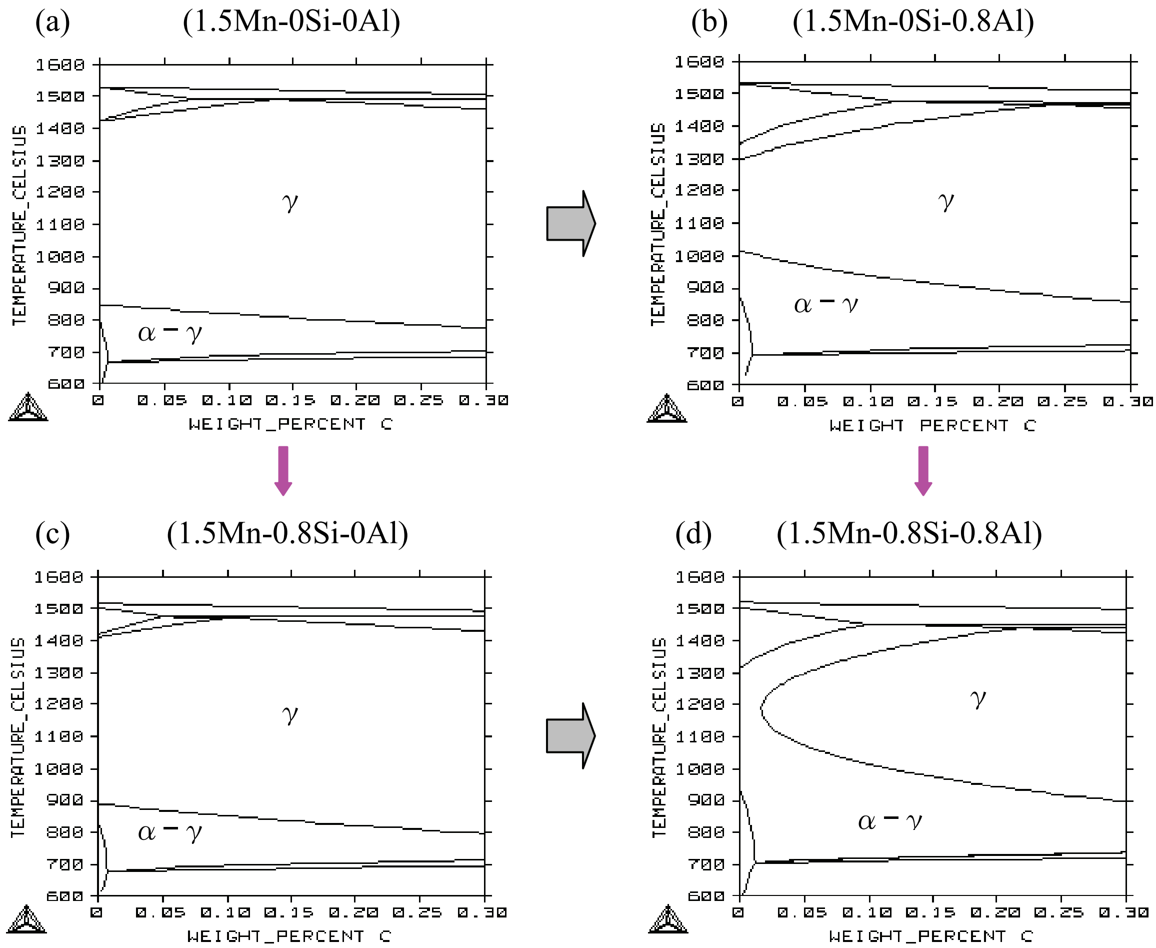

Fig. 1 Phase equilibrium diagrams of Al-Si steels.

Figure 1 shows the structure evolution under equilibrium state, but it does not reflect the structure change under non-equilibrium state. Figures 2 and 3 give the welding CCT diagrams of Al-Si steels, which show the structure evolution at different cooling rates.

The chemical composition (wt%) of the Al-Si steels in Figs. 2 and 3 is 0.08C-1.0Mn-0.8Si-0.8Al and 0.08C-1.0Mn-0.2Si-0.8Al, respectively. Ferrite precipitated at all the cooling rates in Fig. 2, which can decrease the weld bond hardness. The difference in chemical composition between Fig. 2 and Fig. 3 is Si content. When Si decreased from 0.8% to 0.2%, γ phase region enlarged along the temperature axis while α-γ two-phase region shrank. As a result, ferrite precipitation region in Fig. 3 shifted to the high cooling time side and bainite precipitation was promoted.

Effects of grain refining on weld bond toughness

To compensate the decrease in fracture toughness due to the addition of a large quantity of Al and Si, the developed Al-Si weathering steels were grain refined. Grain refining has been verified to

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effectively restrain the toughness decrease and simultaneously increase the strength. Whether its effect is present in the weld bond or not is not well known.

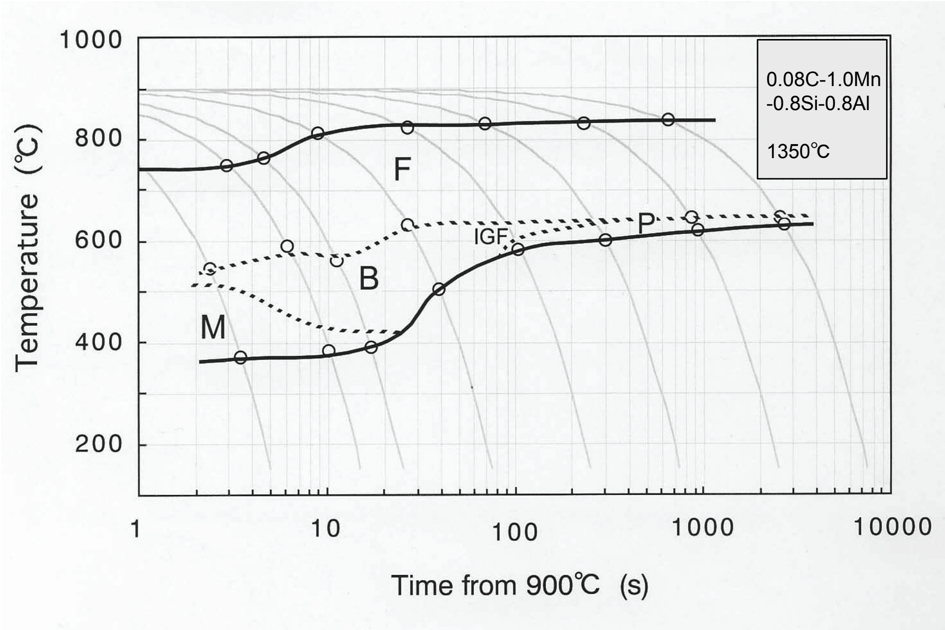

Fig. 2 Welding CCT diagram of 0.08C-1.0Mn-0.8Si-0.8Al (wt%) steel.

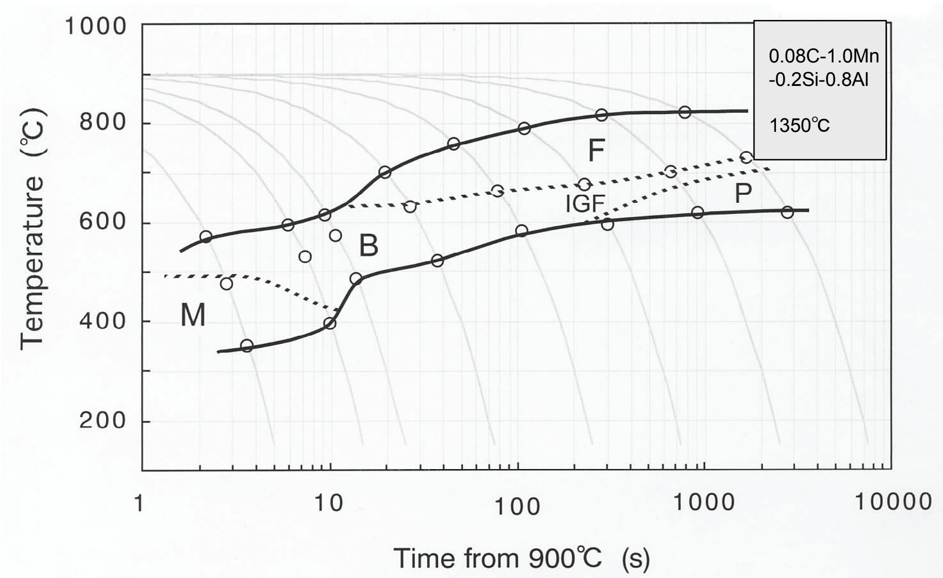

Fig. 3 Welding CCT diagram of 0.08C-1.0Mn-0.2Si-0.8Al (wt%) steel.

Figure 4 shows the results of Charpy impact tests. E_p in Fig. 4 represents the absorbed energy. Simulated weld bond with the cooling time from 800℃ to 500℃ 19sec was used. 0.15C and 0.10C steels are ultra-fine grained steels with ferrite (~1m) and cementite particle, and SM490C is a commercial steel with pearlite and ferrite.

Figure 4 shows that 0.10C steel has the best toughness among the three steels, and 0.15C and SM490C steels have almost the same toughness. The equivalent carbon content, C_{eq}, of 0.10C steel is smallest (0.34), and that of 0.15C and SM490C is almost the same (0.40 and 0.41, respectively) (see Table 1). It can be seen from the experimental results shown in Fig. 4 and C_{eq} that weld bond

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toughness generally decreases with increasing C_{eq}. The fact of which 0.15C steel and SM490C steel have almost the toughness indicates that grain refining hardly affects the weld bond toughness, i.e., the effect of grain refining does not exist in the weld bond region.

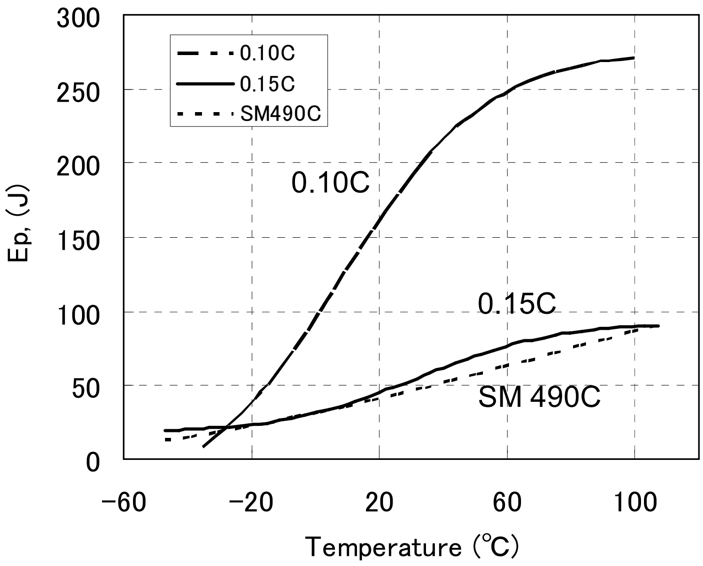

Fig. 4 Charpy impact test results on the simulated weld bond of 0.10C, 0.15C and SM490C steels.

Weld bond toughness of Al-Si weathering steels

It was concluded in the above section that weld bond toughness is mainly determined by the chemical composition of base metal for Si-Mn steels. Figure 5 gives the dependence of weld bond toughness on the equivalent carbon content for Al-Si steels. Absorbed energy, E_p, generally decreases with increasing C_{eq}. However, singular points which did not obey this law are present in

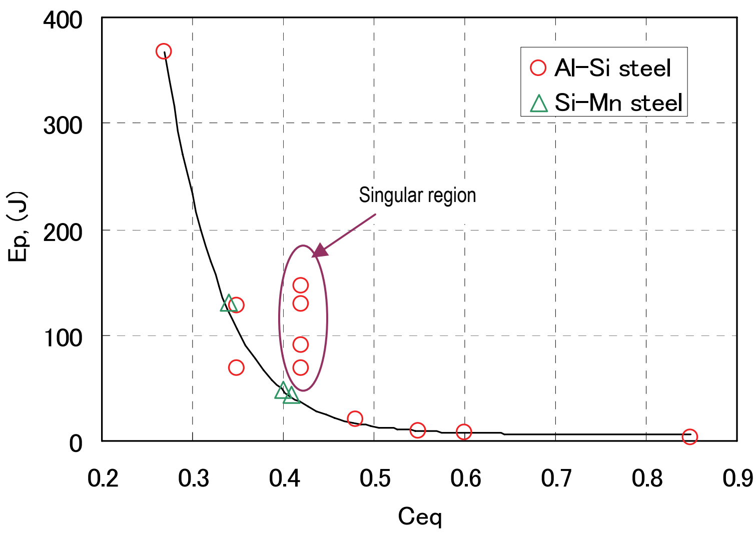

Fig. 5 Relationship between weld bond toughness (E_p, absorbed energy at room temperature) and equivalent carbon content C_{eq}.

Fig. 5.

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The weld bond toughness of Al-Si steels within the singular region was investigated, and the results are shown in Fig. 6. Figures 6(a) and (b) show the dependence of absorbed energy and shear fracture fraction on temperature, respectively. Simulated weld bond with the cooling time from 800℃ to 500℃ 8sec was used in Figs. 5 and 6.

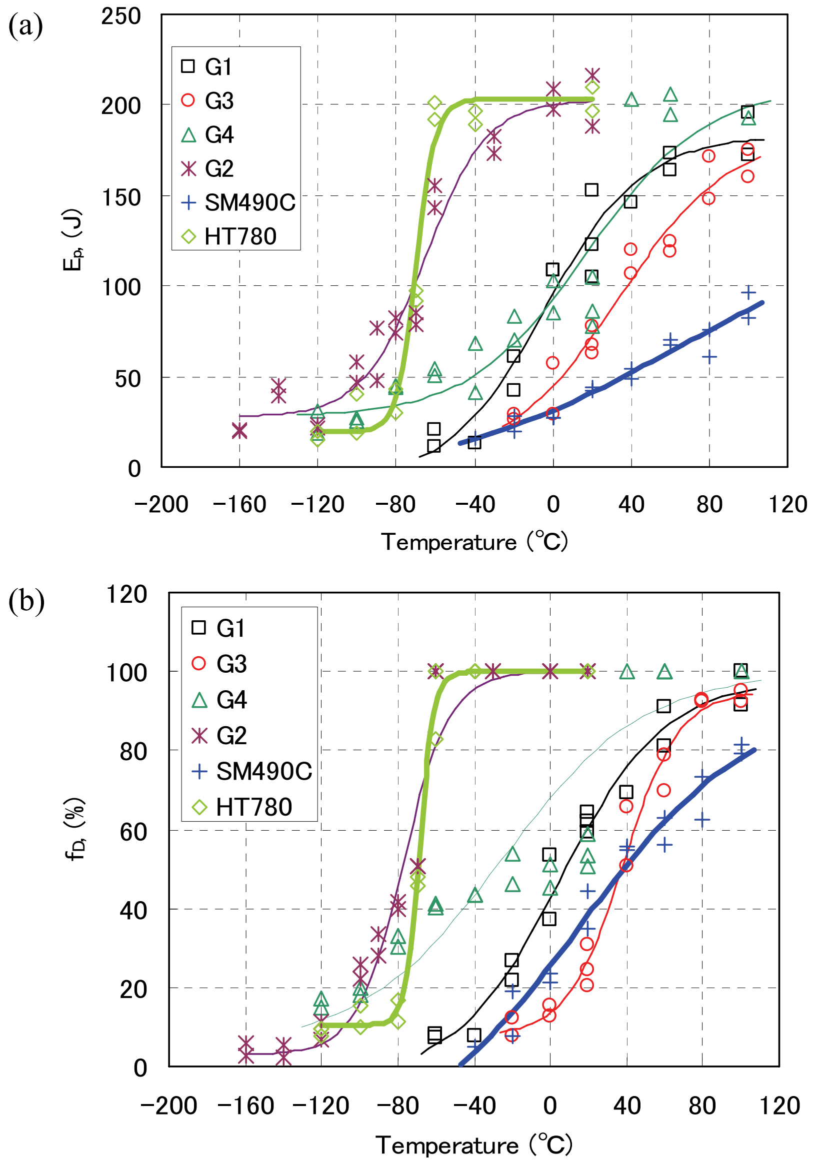

Fig. 6 Charpy impact test results on the simulated weld bond of Al-Si weathering steels. (a) absorbed energy ~ temperature and (b) shear fracture fraction ~ temperature.

Figure 6 shows that the Charpy impact toughness of the Al-Si steels is superior to SM490C steel, which indicates that adding Al and Si is favorable to increase the weld bond toughness. It is known from Table 1 that among the four Al-Si weathering steels G2 and G4 steels have higher carbon content. Comparing with G1, G2 with high carbon content has higher weld bond toughness. The same tendency was shown in G3 and G4. The extraordinary phenomenon of "the higher the carbon content, the higher the weld bond toughness" shows that weld bond toughness can be improved by increasing carbon content for Al-Si steels within a certain C_{eq} range. This special characteristic should be related to the structure change due to Al and Si as shown in Fig. 1, and their correlation is under investigation now.

SUMMARY

1. Grain refining hardly affects the weld bond toughness of steel.
2. Weld bond toughness generally decreases with increasing equivalent carbon content. However, a certain range is present, in which weld bond does not decrease with increasing equivalent carbon content for Al-Si weathering steels. Within this range, the higher the carbon content, the higher weld bond toughness.
3. Al-Si weathering steels have good weld bond toughness.

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