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Microstructural parameter controlling weld metal cold cracking

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ABSTRACT

Purpose: Facing with the practical limitation in lowering diffusible hydrogen content, the possible modification of weld microstructure would alleviate the flux cored arc (FACW) weld deposits from the risk of weld metal cold cracking. Therefore, it was aimed to identify and evaluate the effect of weld microstructure on cold cracking susceptibility of FCAW weld metals, and then to give a basic guideline for designing new welding consumables from the microstructural point of view.

Design/methodology/approach: In order to figure out the parameter(s) that can quantify the microstructural susceptibility of multi-pass weld deposit, two sets of FCAW deposits having tensile strength of about 600MPa were prepared by controlling the Ni content to allow a sufficient variation in weld microstructure but with little change in weld metal strength. Cold crack susceptibility of those two chemistries was evaluated by 'multi-pass weld metal cracking test' at various levels of diffusible hydrogen content.

Findings: All of the cold cracks developed were Chevron-type cracks and the occurrence of such cracks was depending on the proportion of grain boundary ferrite as well as the diffusible hydrogen content. In fact, at the same level of diffusible hydrogen, 1.5%Ni wire showed better resistance to cold cracking than the 0%Ni even though that was higher in strength and carbon equivalent. This result could be explained by the difference in grain boundary ferrite content between those two welds based on the microstructural characteristics of Chevron cracking that preferentially propagates along grain boundary ferrite.

Research limitations/implications: Detrimental effect of grain boundary ferrite against cold cracking has been addressed for Chevron-type cracks that is commonly developed in the ferritic weld metals having 600MPa strength level so that present result may not be valid for higher strength welds over 700MPa which shows vertical-type cracks.

Practical implications: In addition to hydrogen control approach, microstructural modification in a way to reduce the proportion of grain boundary ferrite can be pursued for developing welding consumables with improved resistance to cold cracking.

Originality/value: Proportion of grain boundary ferrite was proposed as a parameter that can quantify the microstructural susceptibility of multi-pass weld deposit. This fact can be used for users and manufacturers in selecting and designing welding consumables with better resistance to cold cracking.

Keywords: Welding; Cold cracking; Weld metal microstructure; Diffusible hydrogen

1. Introduction

Along with the improved resistance to HAZ cracking achieved in modern high strength steels [1], their weld metal becomes more prone to suffer from cold cracking than the HAZ. In particular, weld metal cracking (WM cracking) has been reported to become a major limiting factor in the preheat-free application of advanced high strength steels [2,3].

Table 1.
Chemical composition of FCAW welds and base metal

Material	Chemical composition (wt. %)						P_{cm}(*)
	C	Si	Mn	Ni	Cr	Mo	
0%Ni	0.045	0.55	1.17	0.03	0.03	0.01	0.125
1.5%Ni	0.049	0.42	1.37	1.52	0.03	0.02	0.160
Base Metal	0.079	0.30	1.54	-	-	-	-

Accordingly the phenomena of hydrogen induced cold cracking (HICC) in high strength weld metal has received some attention recently [4-7] but the metallurgical factors that controll WM cracking have not been well understood. In HAZ, it has generally been accepted that HICC will occur given the co-existence of a sufficient quantity of diffusible hydrogen, a susceptible microstructure and a tensile residual stress [7,8]. In order to quantify the susceptibility of HAZ microstructure, various carbon equivalent formulae such as CE and P_{cm} have been suggested [1].

Although WM cracking generally follows the basic rule of HAZ, the quantified parameters that can be used for evaluating weld microstructure are relatively scarce [9]. In 1980's, several workers [10,11] have studied on WM cracking in the multi-pass welds and the preheat temperature necessary to prevent weld metal cracking (T_{WM}) was determined as equation (1):

$$T_{WM}(°C) = A\ Rm + B \log(HD) + C\ h_w + D \qquad (1)$$

In above equation, Rm is the weld metal tensile strength in MPa, HD is the diffusible hydrogen content in ml/100g, h_w is the weld metal height in mm, and A, B, C and D are constants. It is of interest in this equation that Rm was used for the parameter to quantify the microstructural effect to HICC and it is quite different from that generally used for HAZ. Therefore, in this study, it was aimed to evaluate and identify the quantified parameter for weld microstructure with respect to WM cold cracking.

2. Experimental procedures

Two sets of FCAW wires were prepared with different level of Ni content (0%Ni and 1.5%Ni) and the chemical compositions of their weld deposits made with 100%CO_2 gas shielding are reported in Table 1. Both of them are similar in composition except in Ni content. Each set of wires were fabricated to have various levels of HD by changing the moisture content of the flux. HD content of wires was measured by gas chromatograph method following AWS specification.

Multi-pass weld metal cracking test was contucted using a specimen shown in Fig. 1. After the groove was filled, the welded plates were left for about 10 days in the open air then were gouged out from the restraint jig. Ultrasonic test (UT) was performed to check the occurrence of cold cracks along the weld length. Where UT indications were noted, the welded plates were sliced transvesely and examined with scanning acoustic microscope (SAM) to identify the exact location of hidden cracks.

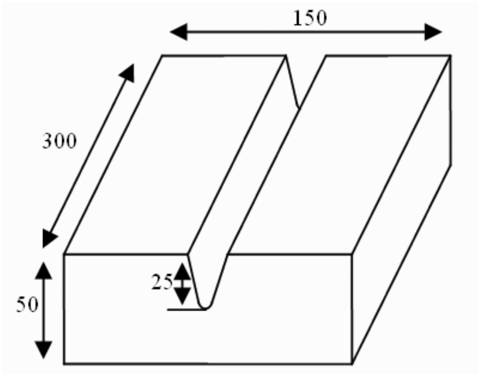

Fig. 1. Geometry of multi-pass weld metal cracking test specimen (unit: mm)

3. Results and discussions

Microstructure of as-deposited weld metals was composed with three major constituents such as grain boundary ferrite(GF), acicular ferrite(AF) and ferrite with second phase(FS) but the proportion of each constituent is quite different depending on the Ni content in weld metal. Quantitative analysis preformed by point counting method is shown in Fig. 2. Mechenical tests have been conducted for both wires using all weld metal test coupons and their results were quoted in Table 2.

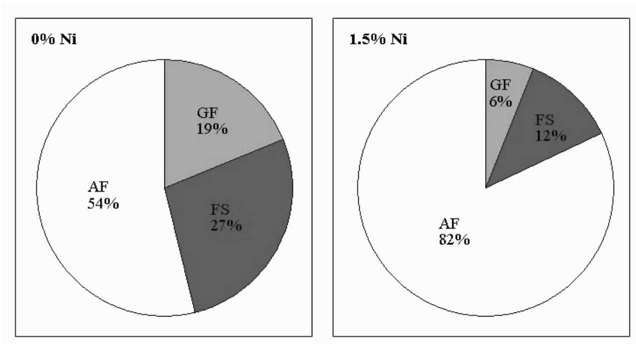

Fig. 2. Quantitative analysis result of weld metal microstructure

SAM picture shown in Fig. 3(a) is a typical image taken from one of the extracted specimens, and the macrograph taken from same specimen is shown in Fig. 3(b). SAM image clearly reveals the size and location of defect. Upon microstructural examination

Table 2.
Results of mechanical tests performed on all weld metal specimens

I.D of wires	Hardness (HR_B)	YS (MPa)	UTS (MPa)	Charpy impact toughness (J)		
				0˚C	-20˚C	-40˚C
0%Ni	95.3	579	611	58	57	27
1.5%Ni	97.7	610	628	94	97	90

performed on the vertical section, the SAM defect revealed in Fig. 3(a) turned out to be a crack that is inclined about 45 deg to the welding direction as shown in Fig. 4. Such characteristics have been well documented for the cold cracks formed in the SAW weld metals and they were called as 'Chevron cracks' [12-15]. Other wires of both chemistries were also tested at various preheating temperatures and their UT results are summarized in Fig. 5. This figure presents the status of HICC occurrence and the number of UT indications. Therefore, border lines that divide cracking (C) and no-cracking (NC) conditions could be drawn as shown in this figure. As a result, it can be concluded that the microstructural change made by Ni addition forces C/NC boundary line down to lower temperature side resulting in better resistance to cold cracking.

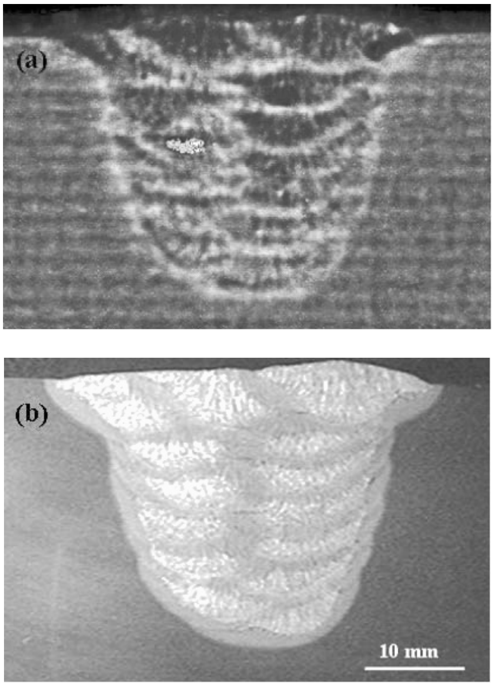

Fig. 3. Weld deposit made with 0%Ni wire having HD content of 4.3 ml/100g at preheating temperature of 40°C; (a) SAM image, (b) macrostructure

In the course of this study, it was demonstrated that HICC found in present FCA welds were Chevron-type cracks which have been known to be developed following the grain boundary ferrite (GF). The mechanism by which Chevron crack develops relating with GF has been well established by many workers [18,19]. Therefore, if the Chevron cracking is the main type of HICC developing in the weld metal, it is quite reasonable to conclude that, as GF phase facilitates HICC, the percentage of GF (%GF) would be more appropriate for a quantitative parameter for estimating the susceptibility of weld metal microstructure with respect to HICC of ferritic weld metal than the ones like carbon equivalent or weld metal tensile strength.

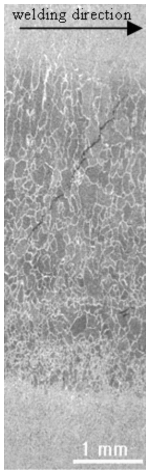

Fig. 4. Microstructure of cracked region taken from the vertical section through the defect shown in Fig. 3

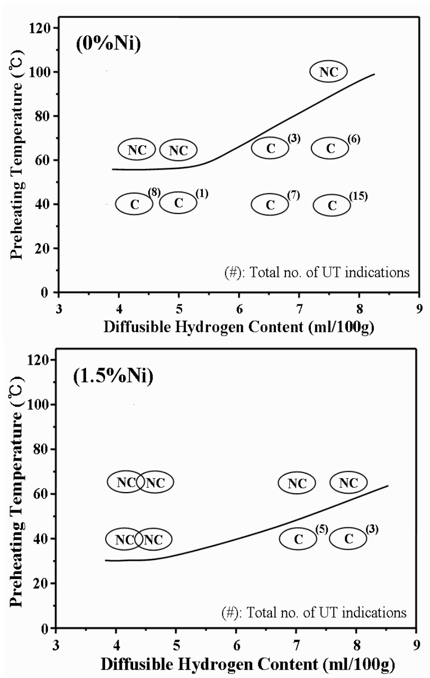

Fig. 5. Result of multi-pass weld metal cracking test

4. Conclusions

From the experimental results, following conclusions could be made:

1) At the same level of HD content, the 1.5%Ni deposit showed substantially better resistance to HICC than 0%Ni one and this difference was concluded to be attributed mainly to the variation in weld microstructure between these two welds.
2) Microscopic analysis showed that all the cracks observed were Chevron-type cold cracks in which GF phase plays an important role as it serves the preferential route for crack propagation. This fact justified the superior resistance of 1.5%Ni deposit as its microstructure contained smaller amount of GF compared with 0%Ni deposit.
3) Microstructural parameters based on weld metal chemistry like carbon equivalent or on weld metal strength failed to explain the difference in HICC resistance of FCAW deposits studied in this investigation. Therefore, when HICC occurs with Chevron-type cracking, a new parameter represented by the percentage of GF (%GF) was proposed so that the HICC susceptibility of weld microstructure can be quantified.

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