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Characteristics of Sulfide Stress Corrosion Cracking of High Strength Pipeline Steel Weld

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The sulfide stress corrosion cracking (SSCC) resistance of API X70 grade steel weldment has been studied using SSCC test in NACE TM-0177 method A. Also, microstructures and hardness distribution of weldment was investigated. The microstructure of SAW joint composed ferrite, pearlite and some MA constituent. Instead of hardening in CGHAZ, softening on the HAZ near base metal occurred. The low carbon TMCP type steel used for SAW showed softening behaviour in the HAZ adjacent to base metal, which was known to be closely related with the SOHIC (stress oriented hydrogen induced cracking). The SSC testing revealed that the API X70 SAW weld was suitable for sour service, satisfying the NACE requirements. By suppressing softening in the ICHAZ region, the SSCC resistance of low carbon TMCP steel welded joints could be more improved.

Keywords : *stress corrosion cracking, sulfide, pipeline, weld, HAZ, SAW*

1. Introduction

Petroleum and natural gas system contaminated with aqueous H_2S are very aggressive to the steels used in the transport and processing of these products. In the presence of applied stress and residual stress, the failure process can occur either by sulfide stress corrosion cracking (SSCC), through hydrogen embrittlement or stress oriented hydrogen induced cracking (SOHIC). The SSCC occurs mainly API linepipe grades steels.[1]

The resistance of linepipe steels to SSCC is related to the microstructures. Elongated MnS inclusions are the susceptible sites for SSCC initiation as hydrogen atoms can easily accumulate at the interface between the steel matrix and non-metallic inclusions. Under the same strength level, microstructural changes from ferrite/pearlite mixtures to tempered martensite in the steeel are effective in improving its SSCC resistance.[2] It has been also noted that low carbon bainite of low carbon bainite/ferrite mixtures can improve the SSCC resistance of the linepipe steels.

In general, the heat-affected zone (HAZ) of a weld is apt to be hardened during welding. The hardened microstructures are usually sensitive to hydrogen-induced cracking (HIC) and stress corrosion cracking (SCC). To avoid the formation of such susceptible microstructures. the carbon equivalent or the alloying element additions have to limited.[2] Significant advances in the steel-making process have been achieved by the combination of the controlled rolling with on-line accelerated cooling process, which is generally known as thermo - mechanical control process (TMCP). The microstructures of TMCP steels are could be significantly refined by rapid cooling, resulting in a remarkable improvement on strength and toughness of the steels.

On the other hand, the oil and gas industries have increasing need for the use of HSLA steels due to the cost savings they afford, especially in long piping systems that transport crude oil or natural gas. Welding processes are utilized to both produce pipeline segments (seam and spiral welds) and join pipeline segments (girth welds) in the field. The performance of HSLA pipeline steels in sour environments depends on the steel grade and may be strongly affected by the presence of a weld which may enhance susceptibility to SSC cracking. An important aspect of HSLA weld hydrogen degradation is that cracking has both sulphid estress cracking (SSC) and stress oriented hydrogen induced cracking (SOHIC) characteristics. Typically, SSC occurs in the hard HAZ area and is oriented perpendicular to the applied stress. SOHIC, however, occurs in the softer base material or the softened HAZ regions, which, under load, experiences strain localization owing to local softening.[5]

This study focuses on the mechanical performance and

SSC resistance of seam welds for pipeline segments. In an attempt to study a low carbon-low carbon equivalent TMCP type API-X70 grade steel was welded by the conventional tandem submerged arc welding and a hybrid welding with the combination of 2 kW Nd-YAG laser power and 1.2 kW GMAW power, and metallurgical, mechanical and SSCC characteristics for both seam welds were evaluated.

2. Experimental procedure

A low carbon-low carbon equivalent TMCP type API-X70 grade steel with a 15 mm thickness were used in this study. The carbon equivalent CE(IIW) and the cracking parameter Pcm was 0.37% and 0.14%, respectively. The CE parameter strongly influences the hardness of the completed weld and the HAZ, which, in turn, will determine the weld'd suitability for sour service, according to NACE MR 0175 and TM 0177. The Pcm, on the other hand, provides a measure of resistance to weld hydrogen cracking. From these token, the present material was estimated to reveal an excellent weldability and resistance to sour service. The as-received mechanical properties, such as yield strength and tensile strength, of the X70 grade steel were 515 MPa and 595 MPa respectively, which satisfied the requirement of the relevant specification.

To investigate the effect of welding process on microstructure and hardness distribution, the laser-arc hybrid welding and submerged arc welding(SAW) were performed. Fig. 1 shows the experimental configuration of the submerged arc welding system with 2 electrode. Welding conditions are shown in Table 1. Fig. 2 shows shapes of groove for the submerged arc welding processes. Both side single pass SAW was carried out with a heat input of about 15 kJ/cm and a welding speed of 1 m/min. On the other hand, the laser equipment is a lamp pumped type Nd:YAG laser welder with a maximum output power of 2 kW (Trumpf Corp.). A prototype weld head is made up of the unification of a laser head and an arc torch, which was constituted of the preceding laser beam and the escorting arc. Laser power was 2 kW and arc welding voltage and current were 20 V and 150 A with a welding wire of 1.2 mm , while the welding speed was 0.3 m/min. The torch inclination angle in relation to the laser beam was 18. As a potential processing parameter, the distance between the laser beam and the arc was changed. The microstructures in welds were observed with optical microscopy using an etchant of 3% nital solution. Hardness data were obtained from a conventional hardness tester using 5 kg load on weldment. Tensile SSCC tests set in NACE TM 0177-96 Method A were carried out with the welded joints of SAW.

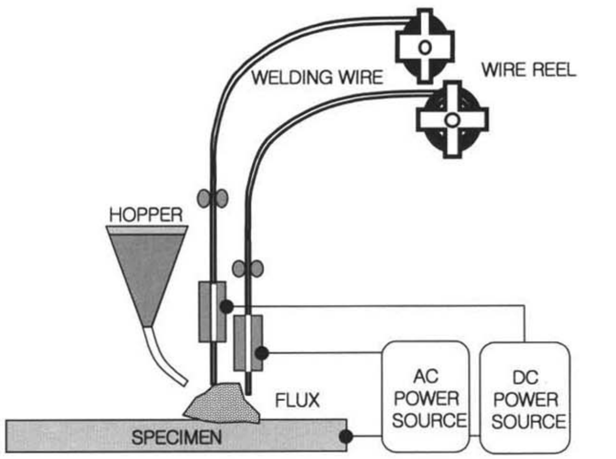

Fig. 1. Experimental configuration of submerged arc welding process used in this study.

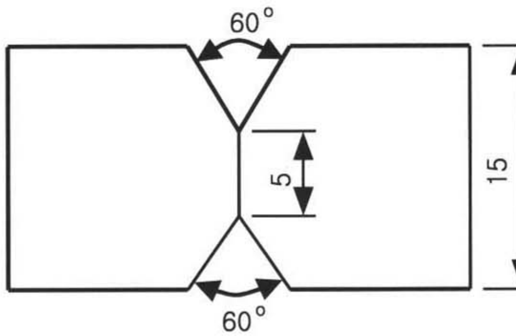

Fig. 2. Groove shape of the SAW.

Table 1. Welding conditions for hybrid welding used in this study.

	Heat Input(kJ/cm)		Total
	DC	AC	
Inside	15	14	29
Outside	16	15	31

3. Results and discussion

3.1 Microstructural variations in welds

The as-received microstructure of the X70 grade pipe steel consisted of fine-grained ferrite and a small volume fraction of pearlite as shown by the longitudinal section in Fig. 3. A heavily banded center line segregation region was not discretely observed. This microstructure was

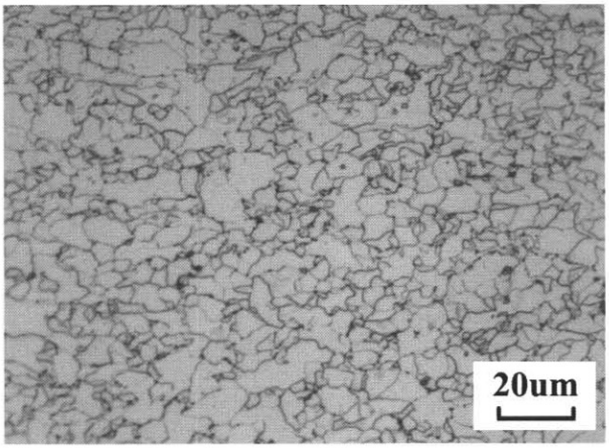

Fig. 3. A typical microstructure of base metal showing a fine grain ferrite matrix and a small fraction of pearlite.

mainly resulted from the chemical composition having a low carbon, low carbon equivalent content. The fine-grained ferrite matrix containing a large fraction of newly recrystallized grains indicated that the steel experienced a thermo-mechanical processing.

Among the various microstructural regions in HSLA steel welds, coarse grain heat affected zone(CGHAZ) and inter-critical HAZ(ICHAZ)are the most concerned regions from the SSC point of view. The CGHAZ is typically the hardest region in steel welds and closely related with the occurrence of SSC. The ICHAZ is heated into the α/γ two phase field, allowing the nucleation of small clusters of austenite in the ferrite grain boundaries. SOHIC mainly occurs in this softened ICHAZ region. Therefore, the microstructures in these two regions were compared for the different welding methods.

Fig. 4 shows microstructures of CGHAZ(Coarse Grain Heat Affected Zone) for each welding method. The CGHAZ microstructure in SAW consisted of coarsened bainite and ferrite, while the corresponding region in LAHW was mainly composed of granular bainite. In SAW, larger weld input energies promote longer times at elevated temperature in the CGHAZ, increasing austenite grain growth, whereas more rapid cooling rate in LAHW in conjunction with the large austenite grain size, promotes the formation of bainitic transformation products.

The microstructures in ICHAZ regions were revealed in Fig. 5. The ferrite grain size in this region appeared to be more finer than that of base metal. In spite of having a finer microstucture, SSC has been shown to occur in this softened sub and intercritical HAZ regions when the material is a low strength steel or a low carbon TMCP steel. The SSC(actually SOHIC) is attributed to localized

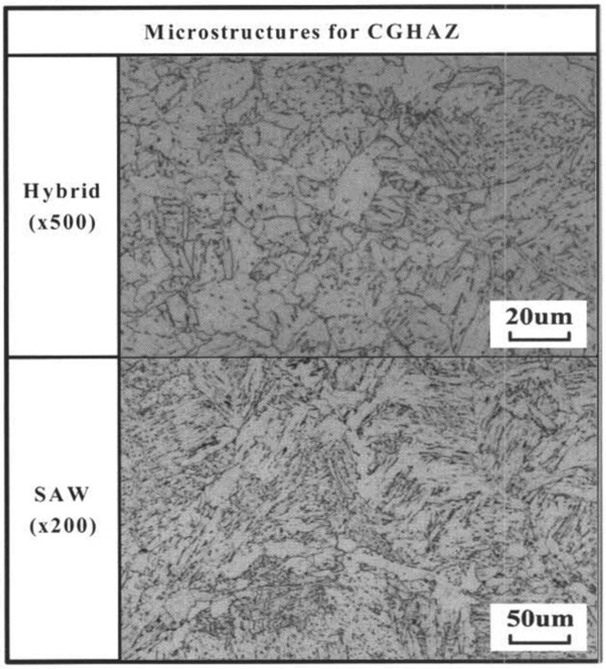

Fig. 4. Comparison of Coarse Grained HAZ microstr- ucture in weldment.

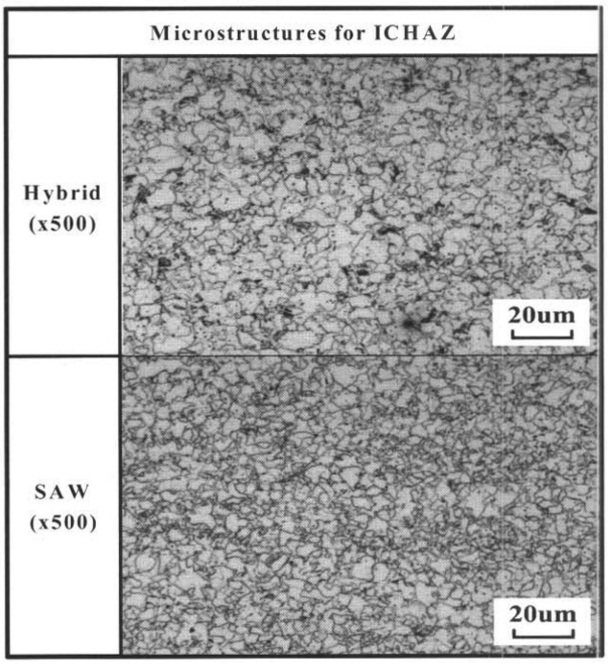

Fig. 5. Comparison of ICHAZ microstructure for each welding method.

softening, which, under load, experiences strain localization.

The microstructures of weld metal on each welding method were compared in Fig. 6. The weld metal microstructure in SAW was typically composed of a coarsened grain boundary ferrite surrounding acicular ferrite, and a small fraction of bainite, while, in hybrid welding, the microstructure revealed a finer acicular ferrite surrounded by grain boundary ferrite formed along the prior austenite

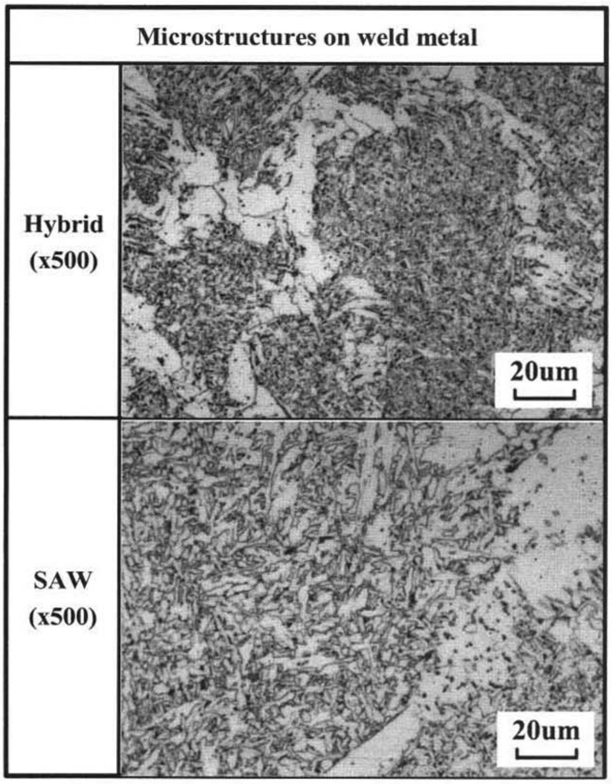

Fig. 6. Comparison of microstructure on weld metal for each welding method.

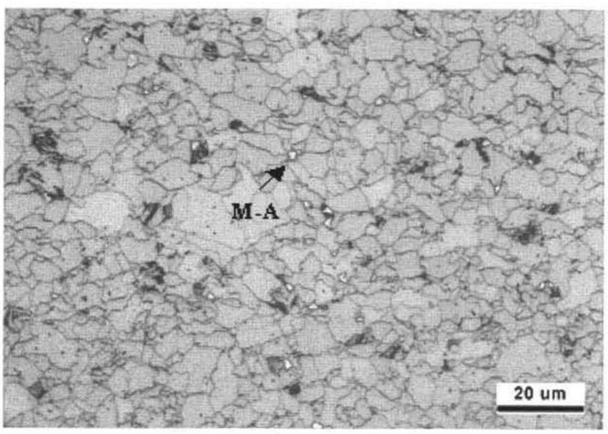

Fig. 7. MA constituent of ICHAZ for submerged arc welding weldment.

grain boundaries. From these microstructural evaluation for the two welding methods, the weld metal in LAHW showed a finer microstructures than those of SAW, which may be mainly attributed to the difference in heat input applied. However, in terms of a volume fraction of grain boundary ferrite, the weld metal microstructure in LAHW seemed to be unfavourable to the toughness.

The intercritical HAZ can be characterized by a high tendency towards formation of Martensite - Austenite constituent (MA). In this study, a small fraction of the MA constituent was observed in the ICHAZ region (Fig. 7).

3.2 Hardness distribution and softening behaviour

The hardness of carbon steels currently determines their fitness for sour environments according to NACE MR0175, which requires that carbon steel and its weldments not exceed a Rockwell C hardness(HRC) of 22 (equivalent to 248 Hv) for these applications. Steels exceeding the HRC 22 threshold are more susceptible to SSC. On the other hand, various HAZ regions in TMCP steels are actually susceptible to softening as welding alters the thermo-mechanical history of the base metal. If the locally softened regions exist in HAZ, SOHIC could be easily happened. Therefore, hardness distribution across weldment was evaluated for the two different welds to investigate the above mentioned hardening and/or softening behaviour.

Fig. 8 shows Vickers hardness distributions for each welding method. Test results show that neither weld exceeded the Hv 248 threshold. The API X70 base metal reveals about Hv 200, while the hardness in weld metal was in the range of Hv 220 ~ 230. Instead of hardening in CGHAZ, softenings on the HAZnear base metal

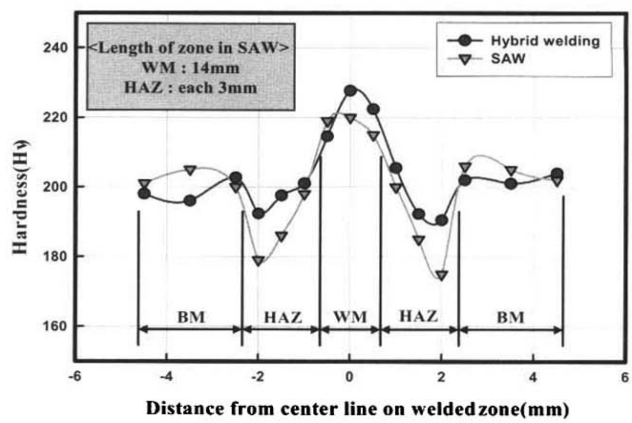

Fig. 8. Distribution of hardness across weldment for each welding method.

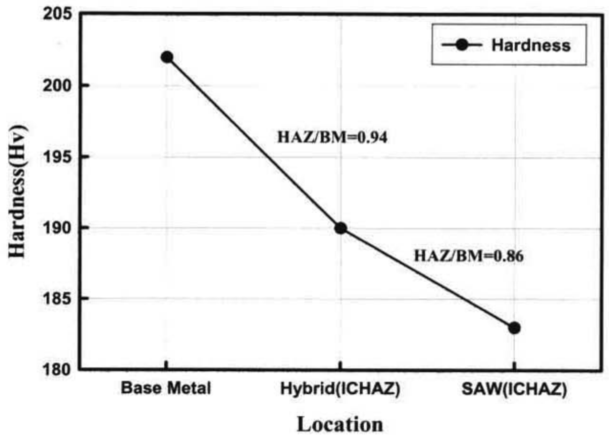

Fig. 9. Comparison of softening ratio in ICHAZ for each welding method.

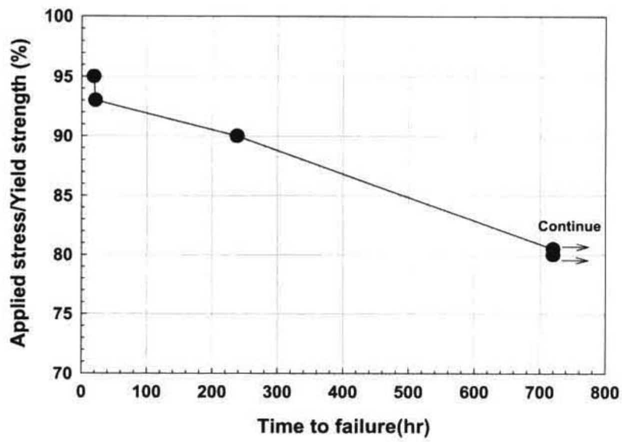

Fig. 10. SSCC test results of API X70 grade steel weldment with 15kJ/cm of heat input.

occurredregardless of welding methods. The softened region was well coincident with ICHAZ regions in each weld.

To clarify the softening behaviour in ICHAZ regions, a hardness ratio of HAZ to base metal was defined for relative comparison (Fig. 9). The ratio of softening on ICHAZ in both hybrid welding and SAW was compared in Fig. 8. The ratio in SAW was about 0.86, indicating that more severe hardness drop was occurred in the conventional SAW. With regard to the different softening ratio obtained from the two welding methods, the ferrite grain coarsening behaviour in ICHAZ was considered to be one of potential reason. Using the microstructures shown in Fig. 5, the average grain size of ferrite in hybrid welding and SAW was measured as 4.08 μm and 5.84 μm, respectively. As expected, smaller heat input energy in hybrid welding promote shorter times at elevated temperature in the ICHAZ, prohibiting ferrite grain growth more effectively.

3.3 SSCC behaviour in SAW weldment

The presence of weldments in linepipe exposed to sour environments significantly affects their susceptibility to SSC, primarily due to localized regions of low toughness or localized strain, in combination with high residual stresses. To investigate the SSCC behaviour of the present API X70 weldments, a series of SSCC test for welded zone in SAW was carried out by NACE TM 0177-96 Method A.

The SSC testing revealed that the API X70 SAW weld was suitable for sour service, satisfying the NACE requirements. All the specimens failed during or after SSC tests showed that the crack was initiated and propagated along the ICHAZ region as a typical SOHIC type. Fig. 11 shows two specimens after SSCC test. The fractured specimen shows a crack path along the ICHAZ regions, while the not-failed specimen after 720h exposure in H_2S solution with 80% yield stress condition also shows continuous microcracks formed along the ICHAZ regions.

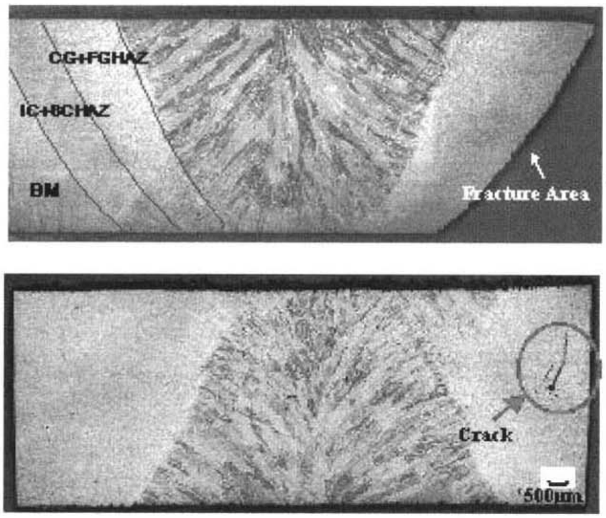

Fig.11. The macrographs showing SSCC tested specimens from SAW weldment.

4. Conclusions

In an attempt to investigate the SSCC resistance of API X70 grade steel weldment, the effect of microsurtucture and hardness distribution were studied.

The main results obtained are as follows :

1) In the present low carbon TMCP steel, a localized softening was occurred in ICHAZ region regardless of

welding method. This may be attributed to ferrite grain coasening and diminishing thermo-mechanical history of base metal during weld thermal cycle.

2) The softening ratio (ICHAZ Hv/Base metal Hv) in SAW was 0.86 which indicated more severe hardness drop occurred in SAW compared to the ratio of 0.94 in hybrid welding. This may be attributed to the different weld input energies.

3) For the present low carbon TMCP type API X70 grade steel, SOHIC in the softened ICHAZ was the main form of hydrogen degradation. So, a minimum HAZ hardness may be justified for these types of steels for sour services.

References

1. R.A. Carnerio, R.C. Ratnapuli, and V. F Cunba Lins, The influence of chemical composition and microstructure of API linepipe steels on hydrogen induced cracking and sulfide stress corrosion cracking, *Materials Science and Engineering A*, **357**, 104 (2003).
2. L.W. Tsay, Y.C. Chen, and S.L.I. Chan, Sulfide stress corrosion cracking and fatigue crack growth of welded TMCP API 5L X65 pipe-line steel, *International Journal of Fatigue*, **23**, 103 (2001).
3. S. Endo, Sulfide stress corrosion cracking in welded joints of welded linepipes, *ISIJ International*, **34**(2), 217 (1994).
4. G.M. Omweg, Effects of welding parameters and H2S partial pressure on the susceptibility of welded HSLA steels to sulfide stress cracking, *Welding Journal*, June 2003, pp.136S~144S.
5. ISO 3183-1 : Petroleum and natural gas industries-Steel pipe for pipelines-Technical delivery conditions-, Part 1 : Pipes of requirement class A, (1996)
6. L.E.Collins, Microstructures of linepipe steels. *Canadian Metallurgical Quarterly*, **22**(2). (1996)