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Research paperResearch Paper

Failure Analysis of Weld Metal Cracking in Weld Joint of API 5L X 75 Pipelines Steel

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Abstract

The development of steel alloy which result thin walled, high strength API 5L X75 grade, a restricting parameter controlling widespread use of X75 is the susceptibility to weld metal tracks. The excellent weld ability of this grade of the pipe steel has enhanced the potential for the use of high strength cellulose consumable like E6010 in root pass welding, but the risk of hydrogen assisted cold cracking (HACC) is also increased because of the high strength weld metal. This investigation outlines , the use of grade (E6010) of commercial cellulose consumable to assess conditions leading to hydrogen assisted cold cracking in the diluted weld metal. The research contained clarification of the link among microstructure; preheat temperature and hardness amounts for the weld consumable and its effect on cracking susceptibility. The cracking morphology studies indicated that there are many ways in which the crack can propagate in the weld metal and HAZ region. The mode of cracking observed was microvoide coalescence.

Keywords: *API 5L X75 , weld metal , cellulose electrode E6010 , HACC , microvoide coalescence*

1. Introduction

The rapid progression toward the use of high strength thin wall pipeline in Iraqi oil field industry. Lying of transmission pipelines still predominantly carried out by using the manual metal arc welding (MMAW) process [1]. During welding the flux decomposes to form a viscous slag which provides a protective layer between the atmosphere and the molten metal. Figure (1)illustrates the (MMAW) process [2].

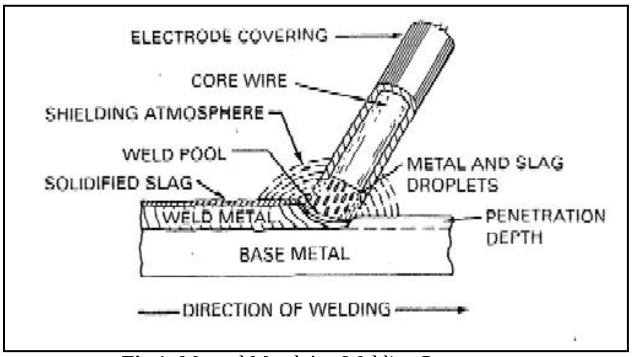


Fig.1: Manual Metal Arc Welding Process

The manual metal arc welding has both advantages ,versatility mobility, cost effectiveness, and limitations are difficulties with high hydrogen weld metal, non continuous welding and requirement for high operator /welder skill [3]. Commercial cellulose electrodes are widely used for high productivity welding for pipeline construction in the oil field industry of south of Iraq. These electrodes contain cellulose (30-40)\%silicates (slag former) and rutile (are stabilizers) which release copious quantities of gaseous hydrogen and carbon mono-oxide around the arc during operation [3]. Hydrogen assisted cold cracking (HACC) was mainly confined to the heat affected zone (HAZ) of weldment [4]. Recent developments in modern structural steels with low carbon content and improved alloy design has shifted the potential cold cracking to the weld metal [5].There are many factors that contribute the (HACC) in the weldment ,weld metal hydrogen ,stress concentration, susceptible microstructure [6]. The weld metal solidifies at high cold rate and hydrogen that has dissolved in fused weld metal is retained in solid state. It is often trapped in the form of gas bubbles (weld metal porosity) [7]. It should be understood that little as 1 ppm of hydrogen in the weld metal can cause cracking problems in high strength steel[8].The highly mobile atoms are trapped at discontinuities in the metal lattice and concentrate at those point. The weld process lead to a non-uniform temperature distribution associated strains and localized plastic deformation .Due to localize ,heating during welding, followed by rapid cooling can generate residual stresses in the weld metal and the HAZ region[9].The interaction between hydrogen content and stress is shown in figure (2)[10].The higher strength low carbon steel whose a acicular ferrite microstructure provide more resistance to (HACC).The figure (3) illustrate steel with relatively tolerant microstructure can exhibit a higher critical stress than stronger steel with sensitive microstructure. Strong steels are more sensitive to hydrogen with regard to both an earlier initiation for HACC and lower critical stress [11].

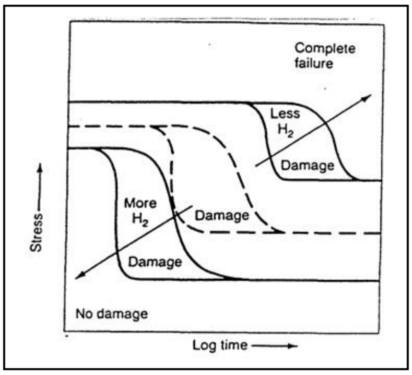


Fig. 2: Effect of hydrogen and stress on damage caused by HACC

In root runs of multi pass welds, the root pass provides a stress concentration with respect to stresses transverse to the weld leading to longitudinal cracks, which are a predominant from of cracking in pipelines [12].Usually in multi pass weld, cracks tend to propagate through ferrite veins from the fusion boundary at an angle of 45° to the direction of tensile force showing a zig zag pattern of cracking called chevron cracking [13].

2. Methods and Process

A thin walled (8.5 mm) API 5L X75 pipe grade steel can provide substantial cost savings in materials and service reliability. All welding process were using the shielded metal arc welding process in the vertical down position with E6010 cellulose electrode. The consumable /electrode strength level consists of a core wire (dia.4 mm) of filler wire and a flux coating composed of various silicates and metal oxides. The weld joint preparation was in accordance with (API guidelines) and details of the dimensions are showed in figure (3) [14]..

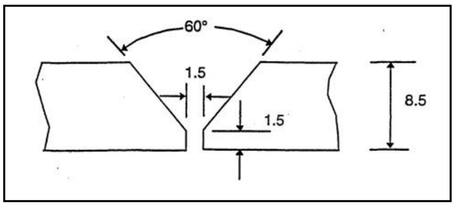


Fig.3: API joint preparation for pipeline welding all dimension in mm

3. Experimental Procedure

The cracked region at the root weld joint was sectioned and mounted in cross-section using standard metallographic techniques. The samples were ground with (400,600,1200) grit size SiC paper and polished using 1 µm Al_2O_3 solution , etching was carried out with (2.5%) nital. Both light microscopy and scanning electron microscopy (SEM) were used to conduct a microstructure study of crack surface, base metal, weld metal. Micro hardness testing was carried out for diluted electrode E6010 weld metal used for root weld joint. Profiles of micro hardness measurement on surface of sample revealed hardness distributions in various constituents such as weld metal, HAZ region and base metal.

4. Results

4.1. Chemical composition analysis

Chemical composition analysis was carried out using Inductively coupled plasma-Atomic Emission Spectrometry for base metal and the diluted weld metal E6010 as shown in table(1).Due to the high dilution of weld metal with X75 base metal (about50%), even under matching electrode such as E6010 can be closed to match the strength of the pipe steel.

Table 1: Chemical composition analysis

	Element																	
Materi-al	Mn	Si	Ni	Cr	C	Mo	Al	Cu	Sn	Nb	Ti	V	B	Ca	N	O	P	S	Fe
API5L75X	1.65	0.26	0.08	0.07	0.025	0.11	0.030	0.21	-	0.068	0.015	0.001	-	0.0008	0.008	-	0.010	0.0025	Bal
Weld metal E6010	1.20	0.24	0.024	0.015	0.105	0.14	0.012	0.01	0.003	0.028	0.02	0.004	<0.0003	0.0005	0.0036	0.049	0.015	0.007	Bal.

4.2 The parameters of welding

The parameters of vertical down ward welding used E6010 electrodes are given in table (2).The principle behind employing different preheat temperatures is to determine the critical crack sensitive preheat temperature for E6010 electrode. A preheat of 35°C was effective in a voiding cracking in root weld metal which also have the advantage of good accommodation of strains induced by residual and thermal stresses during weld cooling.

Table 2: The parameters welding process

Case	Travel speed mm/min	Heat input Kj/mm	Preheat temperature °C
1	316	0.65	22 - 24
2	٤٠٥	0.54	30

4.3 Visual Inspection

Visual examination of the failed sample indicated longitudinal cracking was evident at weld metal region. There was no evidence of branching in the primary crack as shown in Fig. (5).

Fig.5: Surface Longitudinal cracking at weld metal region

4.4 Light optical microscopy

Light optical microscopy at low magnification revealed longitudinal crack in the weld metal at room temperature 22°C. However, it was concluded that crack-free welds are produced with E6010 grade electrodes at 35°C. Figure (6) shows morphology of weld joint.

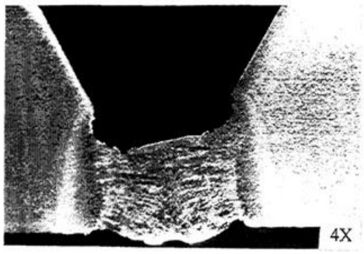


Fig. 6: Morphology of weld joint

4.5 Scanning electron microscopy (SEM)

The weld metal selected section from sample was examined using a Scanning Electron Microscopy. The morphology exhibited by the root weld joint at different regions is evident that the cause of the cracking consisted of columnar grains which are decorated with grain boundary ferrite and ferrite side plates as shown in Fig. (7). A macro-photograph of a select section in Fig. (8) which illustrate the shape of the weld produced using E6010 electrode. The enlarged view of the corresponding section is shown in Fig. (9).The initiation part of cracking occurred in the weldment and was perpendicular to the columnar grain boundaries.

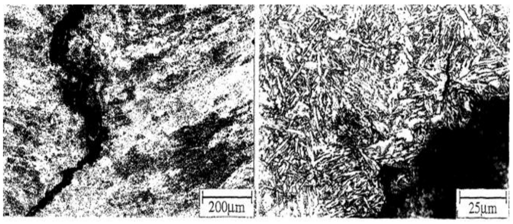


Fig. 7: Microstructure of weld metal
Deposited from E6010 electrode

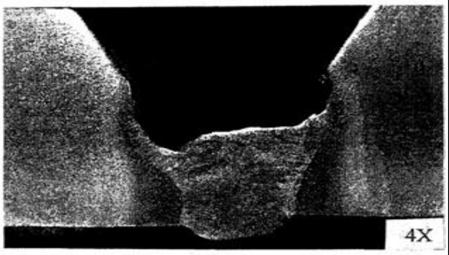


Fig. 8: Macro photograph of the weld joint produce using E6010 electrode

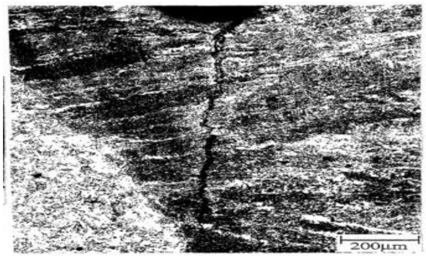


Fig. 9: Enlarge Macro photograph of the weld joint
produced using E6010 electrode

The results of Vickers micro-hardness tests carried out at different regions of the weld metal cross-section sample at preheat temperature of 22°C and 35°C as shown in Fig. (10).The hardness of the HAZ near the fusion boundary towards the weld metal was found to be higher than for the base metal and weld metal. Also base metal hardness values generally exceeded that of the weld metal. From the results, it is evident that the under matching electrode has produced a softer and coarser microstructure than the base metal. Average weld metal hardness is given in table (3).The hardness values for weld metal at different preheat temperature do not show any systematic trend and therefore hardness values cannot be taken as a predictive tool to determine the likelihood of crack in the weld metal.

Table 3: Average weld metal hardness

Electrode type	Preheat Temperature °C	
E6010 micro hardness Hv	22°C	30°C
	252	230

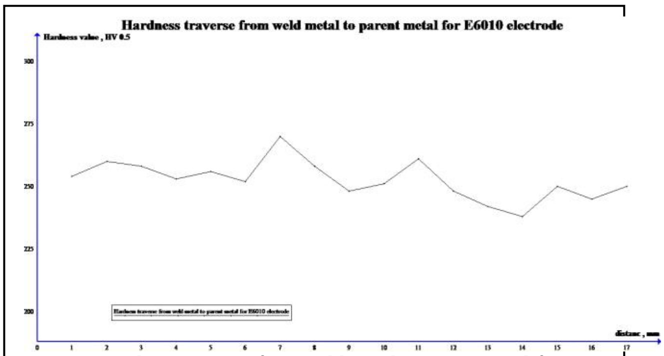
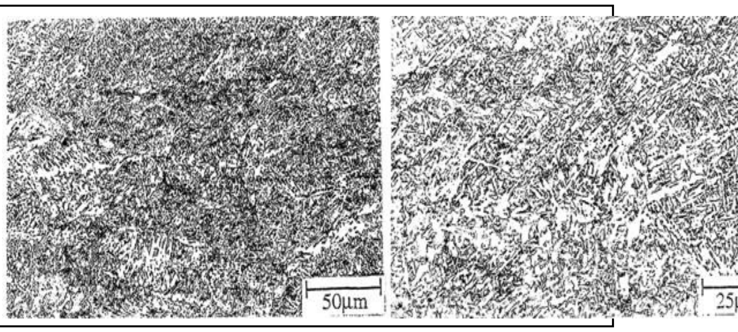


Fig. 10: Hardness traverse from weld metal to parent metal for E6010 electrode

4. Discussion

This investigation clarifies the effect of preheat temperature in cracking behavior using cellulose electrode in 8.5 mm thick API 5L X75 pipeline steel. Weld metal deposited from E6010 showed cracking at room temperature, but not crack with preheat of 35°C or more. It can be assumed that the contribution of preheat to microstructure evolution and hence to the effect of microstructure on cracking will be small. Figure (11) show weld metal microstructure produced from E6010 consumable at two different preheat temperature. The circular ferrite/ bainitic, ferrite structure appeared to be finer without preheat but there was little different in the product phases. Hydrogen is reported to accumulate at stress concentrator such as the root of the weld sometime after welding, when the temperature falls below 200°C .A critical concentration of hydrogen at stress concentrated region can initiate cracking [14]. By preheating the weld zone, the critical concentration of hydrogen may not be reached and so cracking is prevented. This observation suggests that hydrogen has a major influence on crack initiation microstructure of weld metal is 50\% dilution with the API 5L X75 base metal occurred bringing the weld metal composition closer to the base metal. In the section analyzed, crack initiation site was found to be near the weld metal undercut located on the weld surface near the fusion boundary. The transgranular segment of the crack passed through a circular ferrite in the grain interior as shown in Fig.(12).The circular ferrite could not resist crack growth due to the stress raising effect of the crack tip and hydrogen accumulation at the top. Hardness values cannot be used as tools to predict weld metal cracking in this case. A macro photograph showing HACC is given in Fig.(13).An enlarged view of

the crack is shown in Fig.(14).The examination revealed the fracture mode in a circular ferrite was ductile associated with fine microvoide coalescence. Fig.(15) shows the microstructure and corresponding fracture topography.



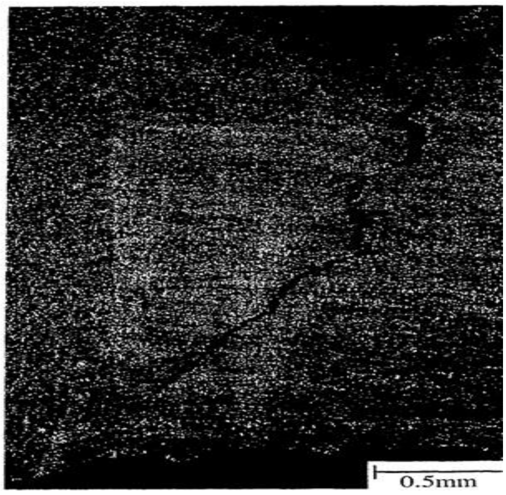


Fig. 12: Crack passed through a circular ferrite in the grain interior

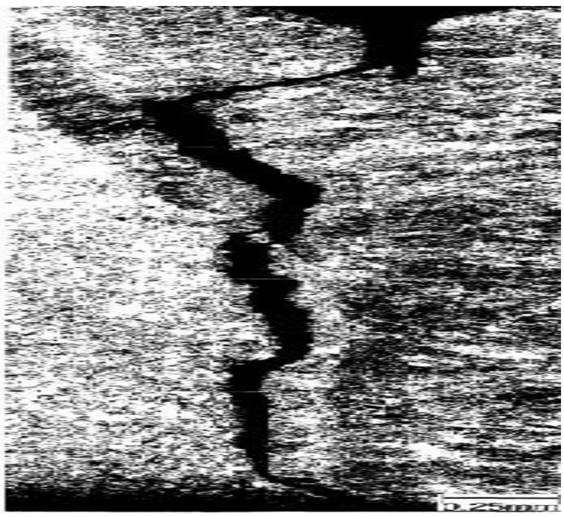
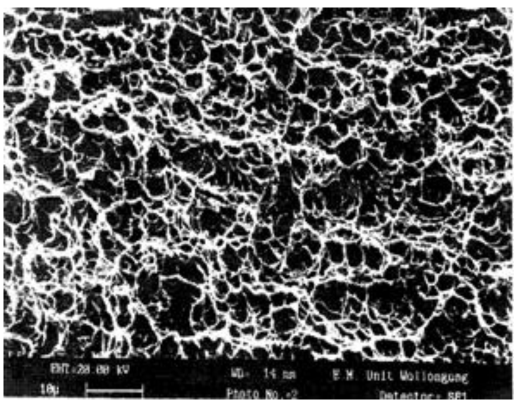


Figure 14: Analysis of crack propagation-enlarged view of the macro photograph

5.



The analysis of the suitability of E6010 cellulosic electrode for root pass welding of API 5L X75 pipeline steel at room temperature exhibited cracking in the weld metal

- Preheat to 35°C or more was found to be effective in avoiding cracking in the weld metal deposited with cellulosic consumable.
- It was found that cracking in the weld metal occurred within 5-10 minutes after welding, when the temperature had fallen below 200°C.
- The hardness value was not sensitive predicator of HACC in the weld metal.
- Crack growth occurred in a transgranular manner a cross the a cicular ferrite, linking up the inter-granular segment.
- From the results obtained with E6010 electrode, it can concluded that in principle it is possible to weld API 5L X75 pipeline steel without hydrogen cracking crack, provided the cooling rate is low enough to allow hydrogen effusion to concentrations lower than the critical concentration for crack initiation.

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