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Effect of Hydrogen on Mechanical Properties of Pipeline Steel Weld Metal

Reza Khatib Zadeh Davani[1], Reza Miresmaeili*[1] and Mohammadreza Soltanmohammadi[2]

1. Department of Materials Engineering, Tarbiat Modares University, Tehran, Iran

2. Enghelab Technical College, Technical and Vocational University, Tehran, Iran

miresmaeili@modares.ac.ir

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INTRODUCTION

According to the long distance and preventing leak of liquids in pipelines, pipelines have to connect together by welding and make sure that welds are without fault [1]. In pipelines, considering the lightness and smallness of hydrogen, it can penetrate through the surface and volume of the material and place in high-energy traps, interfaces, and reversible or irreversible traps. The acicular ferrite microstructure, with its reversible and weak traps of hydrogen, such as dislocation accumulations, traps more hydrogen atoms and shows higher hydrogen concentrations than other microstructures [2-5]. Latifi et al. [3] investigated the effect of the weld metal and the base metal microstructure on the content of hydrogen diffusion. The most diffusive hydrogen was related to a weld metal with an acicular ferritic microstructure and the lowest diffusive hydrogen in base metal was obtained by ferritic matrix microstructure and pearlite / bainite bands. Ballesteros et al. [4] evaluated mechanical properties of X80 pipeline weld metal by 8018G electrode and find that reduction of ductility in Sodium thiosulfate environment by decreasing PH, happened with higher hydrogen production rate and risk of creating cracks. Dong et al. [6] in his studies investigate effect of hydrogen in damage mechanisms and found that by increasing material's strength, the resistance to hydrogen assisted-cracking reduced. Birnbaum [7] at first by precise fracture analysis, suggested that the hydrogen embrittlement of materials was related to the increase of localized plasticity in the crack tip. Because of creating the plasticity on crack tip in lower stress than stress required for deformation in other places, fracture happens without macroscopic deformation; as such, it is nominated as hydrogen embrittlement. Miresmaeili et al [8]. proposed an explanation for softening and hardening of material by hydrogen. They discovered that softening and hardening of material is under the influence of the critical shear stress due to the dislocation slip that depends on the hydrogen content.

EXPERIMENTAL PROCEDURE

WELDING PROCESS

Welding process carried out with rectifier (KEMPPI). The 8018G electrode dried in furnace for 1-2 hours. The welding was carried out in flat position and butt joint design and single V-groove joint with a 38-degree angle (Single V). Interpass temperature was considered to be 200 °C. After the welding process, the samples prepared for PWHT (post weld heat treatment). They reached 600 °C for 4 hours, 2 hours remained at this temperature, and then reached ambient temperature for 4 hours.

SAMPLE PREPARATION

TENSILE SAMPLE

Tensile samples prepared by wire cut according to Figure 1. The notch created in weld metal was for generating stress concentration and triaxiality in weld metal [9].

MICROHARDNESS SAMPLE

The surface of the microhardness test samples, polished with distilled water, detergent solution and Alumina powder (0.3µm) and finally micro-etched by Nital solution.

HYDROGEN PRE-CHARGING PROCESS

Hydrogen charging was performed by 1 normal sulfuric acid solution with 0.25 g/l arsenic trioxide (for preventing accumulation of hydrogen atoms) at room temperature. Electrochemical hydrogen charging carried out at room temperature for 12 h using a 5 mA/cm^2 current density.

TENSILE TEST

The samples were first tested in uncharged (reference) state. Then, to evaluate the effect of hydrogen on their tensile properties, they were placed in the electrochemical cell of hydrogen charging. A tensile test was carried out using a SANTAM machine with a capacity of 100 tons with an extensometer with the speed of 1 mm / min. After the test, the fracture surface of uncharged and charged samples were examined using the SEM (Philips XL30) to evaluate the fracture surfaces.

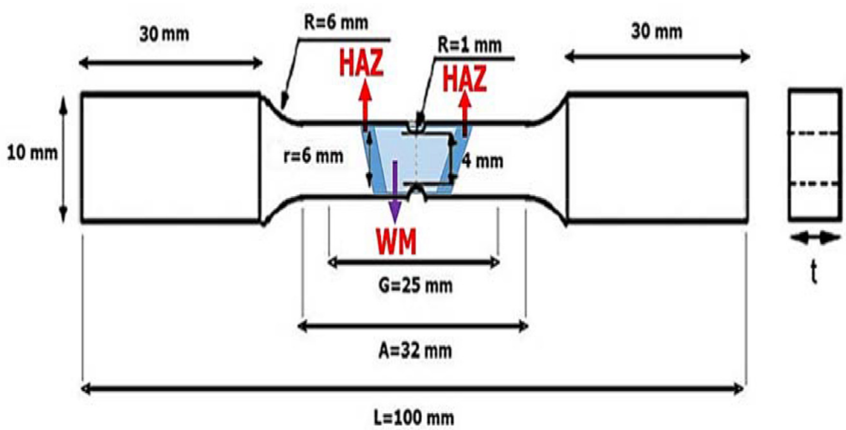

Figure 1: The notched tensile sample of weld metal.

MICROHARDNESS TEST

Microhardness test of the Vickers method was performed with a load of 500 g and 15 seconds of loading time. The hardness of the samples charged was measured immediately after the charging time and at a time interval of 5 minutes, 10 minutes and 30 minutes after charging.

MEASUREMENT OF DIFFUSIVE HYDROGEN

This test was performed using EG & G Model 273A and three electrodes. The sample was immediately assembled on hydrogen de-charging cell as working electrode. The saturated Calomel electrode acts as a reference electrode and Platinum electrode acts as a counter electrode. A constant anodic potential (+168 mV (SCE)) was applied for 1800s (τ_{dis}) and curve of polarization current versus time was obtained. Hydrogen content (CH) was calculated through Eq. (1) and the area between two curves (QH abs). In Eq. (1), units are mentioned in parentheses and z is number of electron contributing to the reaction (in this case, z=1), F is Faraday's constant (F= 96,487 C mol^{-1}) and v is the effective volume which may be obtained from multiplication of exposed surface by thickness of sample [10].

$$C_H = \frac{Q}{zF\nu} \quad (1)$$

RESULTS AND DISCUSSION

WELD METAL MICROSTRUCTURE

Figure 2 shows the weld metal microstructure. According to Figure 2, some acicular ferrite phase accumulated in different regions and some veins appears between them that includes polygonal and quasi-polygonal ferrite. Also these veins nominates as Ferrite vein [11]. Because of some acicular ferrite in weld metal microstructure, it has sufficient mechanical properties. Small grain size in weld metal has a great role in strength properties improvement. Also percentage of hard phases (including bainite and pearlite) improves strength properties.

Figure 3 illustrates the current polarization curve. According to Eq.1, the amount of diffusive hydrogen in weld metal using Figure 3, is measured as 1.5E-06 mol/cm^3.

The major weld metal microstructure is acicular ferrite. The amount of hydrogen trapping in acicular ferrite is more than amount in ferrite-pearlite banded/bainite microstructure, but has lower sensitivity to hydrogen cracks [12]. Microstructure traps has major role in hydrogen diffusion. The concentration of hydrogen diffusion is related to strong reversible traps such as precipitations, pearlite/ferrite interface or ferrite/cementite interface [13-14]. Traps such as voids, grain boundaries (with large angles), dislocations, inclusion and precipitation cause hydrogen accumulation in the material and form hydrogen molecules which finally lead to defects [15-16]. HIC appear in some region that hydrogen blisters appears. Voids create in interfaces between non-metallic and metal lattice due to the difference in thermal expansion coefficient and hydrogen enters these traps. Hydrogen sometimes move through ferrite lath, grain boundaries and interfaces [6, 12]. The smaller the grain, the higher the hydrogen content will be due to more trapping.

EVALUATE THE STRENGTH PROPERTIES OF WELD METAL IN THE PRESENCE OF HYDROGEN

Figure 4 shows tensile curve of weld metal. All samples fractured from notched and in gage length due to triaxiality and stress concentration.

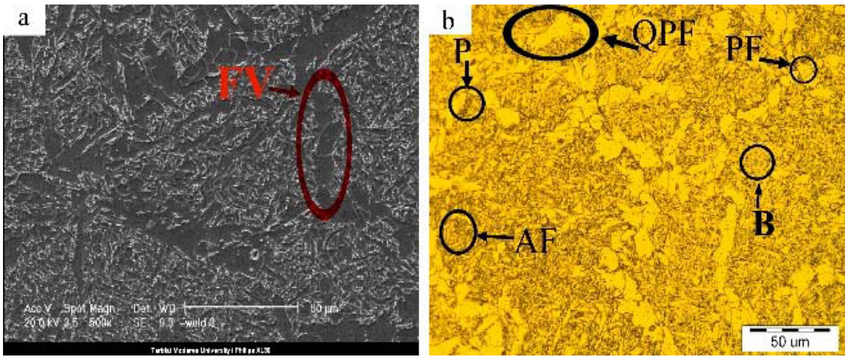

Figure 2: weld metal microstructure obtained by a) optical microscopic b) SEM.

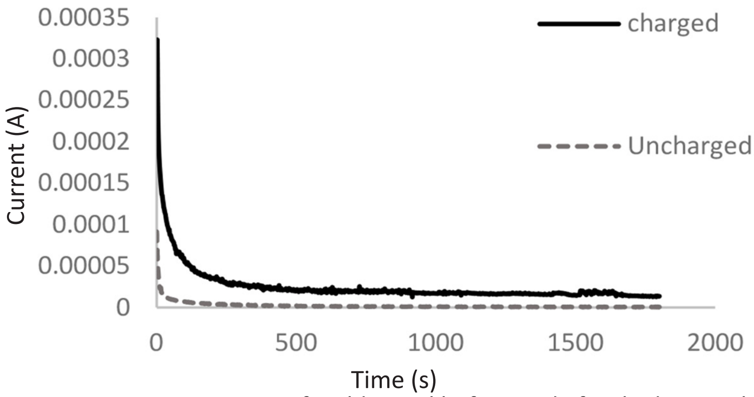

Figure 3: Current-time curves of weld metal before and after hydrogen charging.

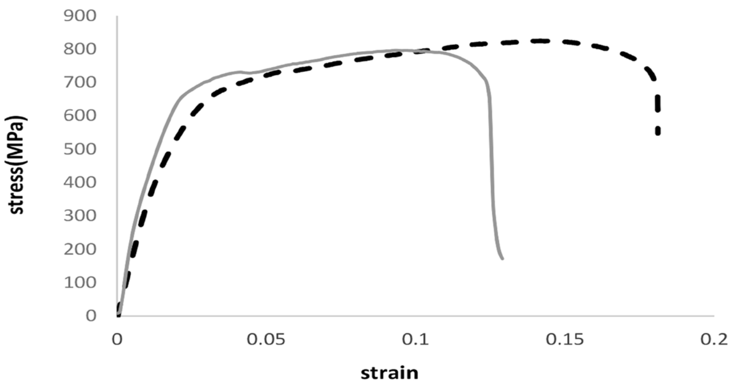

Figure 4: stress-strain curve of weld metal in charged (solid line and uncharged sample (dashed line).

Notch can increase triaxiality and another reason for increasing strength properties of weld metal is due to the strengthening phenomenon due to notch. After hydrogen charging, UTS decreased by 5%, yield strength increased by 16% which indicates hardening in the presence of hydrogen. By hydrogen diffusion, dislocations move and cause local plasticity. Hydrogen promotes localized plasticity in some regions and in micro-scale, so they are fractured locally, but in macro-scale plastic deformation and as a result softening does not happen. These phenomena lead to hardening.

According to Figure 5, microscopic fracture cross-section of uncharged sample (b) has a lot of dimple and fine voids. But in charged sample (d) in microscopic mode, there are more flat surfaces and river marks, which indicate a brittle fracture. Due to the charge of hydrogen, the ductile fracture percentage of all base metal samples was reduced by an average of 60% which indicates brittle fracture. The higher amount of elongation and reduction of cross section area in uncharged samples indicate softening and more necking than charged samples.

EFFECT OF HYDROGEN ON WELD METAL MICROHARDNESS

The results of weld metal microhardness in both charged and uncharged samples in indirect mode shows in Figure 6. The hardness of weld metal in the presence of hydrogen increased by 12%. Recent studies reported that hydrogen lead to hardness increasing [3, 10]. Immediately after charging, the hardness increased, while after that, the hardness decreases, which has a direct relation with reducing the amount of hydrogen in the material. Hydrogen prefer to diffuse in strong traps, then go into weak traps because of no empty place. Hydrogen atoms acts as a locked dislocation traps on the surface which indicates hardening. One of the weak traps is dislocation that hydrogen atoms inevitably lean towards them and produce hydrogen atmosphere around dislocations, so dislocations are pinned and the stress for plastic deformation increases. This phenomenon is called hardening [17].

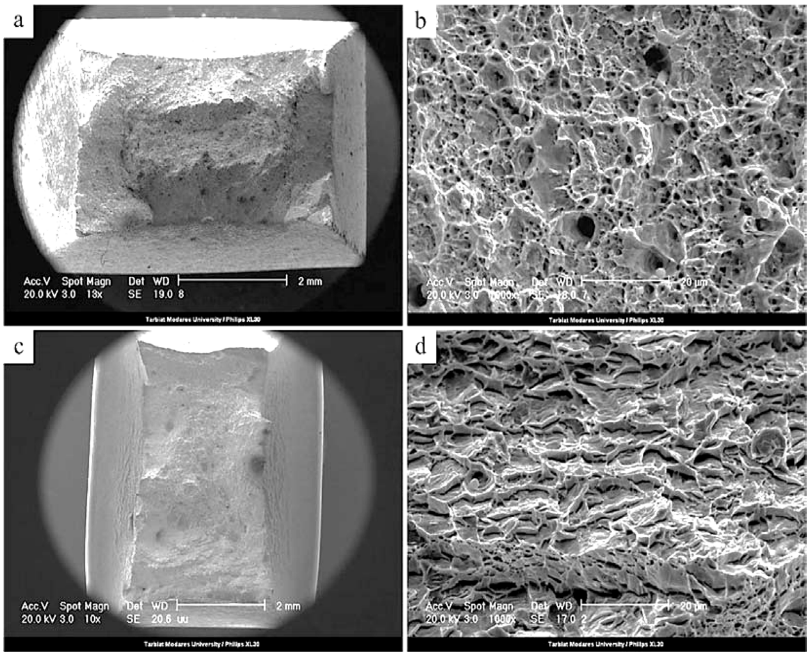

Figure 5: SEM photos of weld metal samples fracture a) uncharged macroscopic mode, b) uncharged microscopic mode, c) charged macroscopic mode, and d) charged microscopic mode.

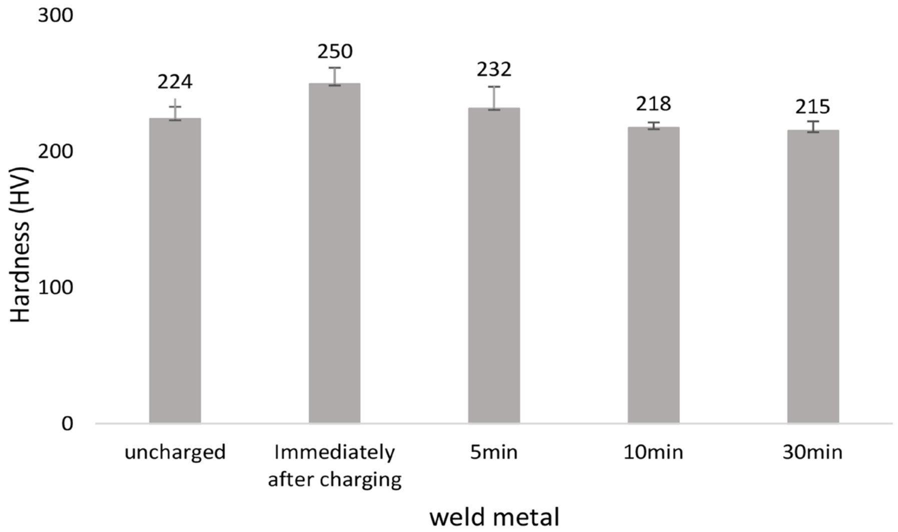

Figure 6: results of weld metal microhardness in the presence of hydrogen in indirect charging.

CONCLUSIONS

1. According to the microstructure of weld metal, some acicular ferrite phase accumulated in different regions. Also there are some polygonal and quasi-polygonal ferrite, bainite and pearlite phases. Because of existence of some acicular ferrite and sufficient trap in this phase, the amount of hydrogen diffusive is more than others. The amount of diffusive hydrogen in weld metal is measured as 1.5E-06 mol/cm^3.

2. In the presence of hydrogen, yield strength increased by 16% indicating hardening. Hydrogen diffuses and causes localized plasticity, but plastic deformation does not happen in macroscopic scale which indicates brittleness.

3. According to the results of fractured cross-section, uncharged sample has a lot of dimples and fine voids. But in charged sample, there are more flat surfaces and river marks, which indicate a brittle fracture.

4. In the presence of hydrogen, weld metal microhardness increased by 12% in indirect hydrogen charging.

REFERENCES

[1] RamezanKhani A., “Pipe line welding,” Gharn Publication, Tehran, 2012. (In Persian)

[2]. Stroe M., “Hydrogen Embrittlement of Ferrous Materials”, 2006.

[3]. Latifi A., Miresmaeili R. and Abdollah Zadeh A., *“The mutual effects of hydrogen and microstructure on hardness and impact energy of SMA welds in X65 steel,”* Materials Science and Engineering A, Vol. 679, 2 January 2017.

[4]. Ballesteros A., Ponciano J. and Bott I., *“Study of the susceptibility of AP5L X80 girth welds to sulfide stress corrosion cracking and hydrogen embrittlement,”* 8th International Pipeline Conference IPC2010.

[5]. Hardie D., Charles E. A. and Lopez A. H., *“Hydrogen embrittlement of high strength pipeline steels,”* Corrosion Science, Vol. 48 , pp. 4378–4385, 2006.

[6]. Du X.S., Cao W.B., Wang C.D., Li S.J., Zhao J.Y., Sun Y.F., *"Effect of microstructures and inclusions on hydrogen-induced cracking and blistering of A537 steel,"* Materials Science and Engineering A 642, pp. 181–186, 2015.

[7]. Birnbaum K., *"Mechanisms of hydrogen related fracture of metals,"* Technical Report, 1989.

[8]. Miresmaeili R., Liu L., Kanayama H., *"A possible explanation for the contradictory results of hydrogen effects on macroscopic deformation,"* Int. J. Press. Vessel. Pip. 99–100, pp. 34–43, 2012.

[9]. Bridgman P. W., Studies in large plastic flow and fracture, McGraw-Hill New York, 1952.

[10]. Khatib Zadeh Davani R., Miresmaeili R., Soltanmohammadi M., *"Effect of thermomechanical parameters on mechanical properties of base metal and heat affected zone of X65 pipeline steel in the presence of hydrogen,"* Materials Science and Engineering A, Vol. 718, pp. 135-146, 2018.

[11]. Lunarska E., Ososkov Y., Jagodzinsky Y., *"Correlation between critical hydrogen concentration and hydrogen damage of pipeline steel,"* International Journal of Hydrogen Energy, Vol. 22, No. 2–3, pp. 279-284, 1997.

[12]. Ghomashchi R., Costin W., Kurji R., *"Evolution of weld metal microstructure in shielded metal arc welding of X70 HSLA steel with cellulosic electrodes: A case study,"* Materials Characterization, Vol. 107, pp. 317–326, 2015.

[13]. Koh S., Lee J., Yang B., Kim K., *"Effect of Molybdenum and Chromium Addition on the Susceptibility to Sulfide Stress Cracking of High-Strength, Low-Alloy Steels,"* Corrosion, Vol. 63, pp. 220-230, 2007.

[14]. Zhao Y., Seok M.Y., Choi I.C., Lee Y.H., Park SJ., Ramamurty U., Suh J.Y., Jang J.i., *"The role of hydrogen in hardening/softening steel: Influence of the charging process,"* Scripta Materialia, Vol. 107: pp. 46-49, 2015.

[15]. Jia H. A., Hung M. Richard H., Gangloff P. J., Scully R., *"Hydrogen diffusion and trapping in a precipitation-hardened nickel–copper–aluminum alloy Monel K-500 (UNS N05500),"* Acta Materialia, Vol. 61, pp. 3186–3199, 2013.

[16]. Kong J., Zhen L., Guo B., Li P., Wang A., Xie C., *"Influence of Mo content on microstructure and mechanical properties of high strength pipeline steel,"* Material Design, Vol. 25 :pp. 723-8, 2004.

[17]. Chu W.Y., Qiao L.J., Li J.X., Su Y.J., Yan Y., Bai Y., Ren X.C., Huang H.Y., *"Fatigue crack growth acceleration caused by irreversible hydrogen desorption in high-strength steel and its mechanical condition,"* Materials Science and Engineering, Vol. 528, pp. 7729–7738, 2011.