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EFFECT OF HYDROGEN CONTENT ON HYDROGEN EMBRITTLEMENT OF API X70 STEEL

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Abstract: The effect of hydrogen content on hydrogen embrittlement of high toughness API X70 line-pipe steels was studied. The hardness of conventional API X70 steel was measured before and after hydrogen charging. The various hydrogen contents for API X70 steel were charged at 10MPa gas pressure. The tensile test for hydrogen charged API steel was conducted at room temperature. The hardness increased slightly with hydrogen content. The fracture surfaces were changed from dimple type to quasi-cleavage type with hydrogen content. And external cracks were observed just only at 100% hydrogen content.

Keywords: API X70 steel, hydrogen embrittlement, fracture surface, hardness.

1. INTRODUCTION

API X70 pipeline steel for natural gas transportation is a kind of the high strength low alloy (HSLA) steels to satisfy the mechanical properties such as high tensile strength, high toughness [1]. During the usage of API X70 steel as pipeline structural material, hydrogen embrittlement would be occur for hydrogen contained in natural gas. Several researches were conducted about the hydrogen embrittlement mechanisms of API pipeline steels [2-7], however, only a few data were published about the effect of hydrogen content on fracture behavior of API X70 steel [8]. The aim of this study is to investigate the effect of hydrogen content on hydrogen embrittlement of API X70 steel.

2. EXPERIMENTAL PROCEDURES

The used material was conventional API X70 steel with chemical composition (wt.%) of 0.26%C - 1.65%Mn - 0.03%P - 0.03%S - 0.5%Cr - 0.5%Ni - 0.5%Cu - 0.15%Mo - (Nb+V+Ti)≤0.15% - balance Fe. Samples were obtained from the base metal of received pipeline with the diameter of 762mm and the thickness of 15.9mm. And sampling direction was transverse to the longitudinal direction of pipeline.

Tensile test was performed within pressure vessel filled with air (0% hydrogen), 1% hydrogen + 99% methane, 30% hydrogen + 70% methane and 100% hydrogen gas under 10MPa gas pressure and then held 30 minute before test at room temperature, respectively.

ASTM G142 type tensile specimens (diameter 6.0mm, gage length 28.6mm) were prepared and the deformation rate was 0.12mm/min.

Fracture surfaces and failure shapes of the tensile tested specimens were observed using a Stereoscopic Microscope, a Scanning Electron Microscope (SEM, Quanta 200 FEG) in order to investigate the fracture modes of API X70 steel.

Rockwell B scale hardness test (loading 100 kg for 10 second) was performed at room temperature to measure the hardness of API X70 steel with different hydrogen contents.

3. RESULTS AND DISCUSSION

3.1. Hardness change with hydrogen content

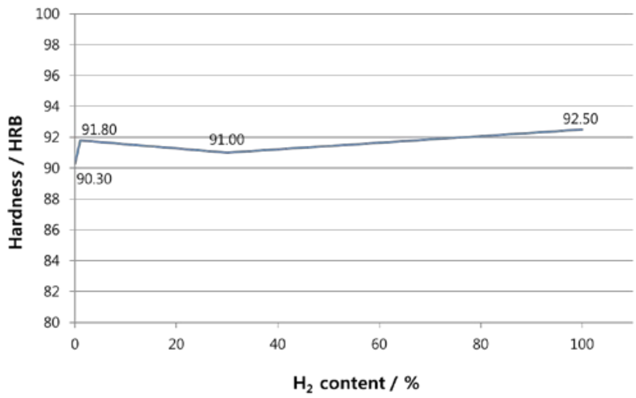

Fig. 1 Rockwell hardness changes of API X70 steel with hydrogen content.

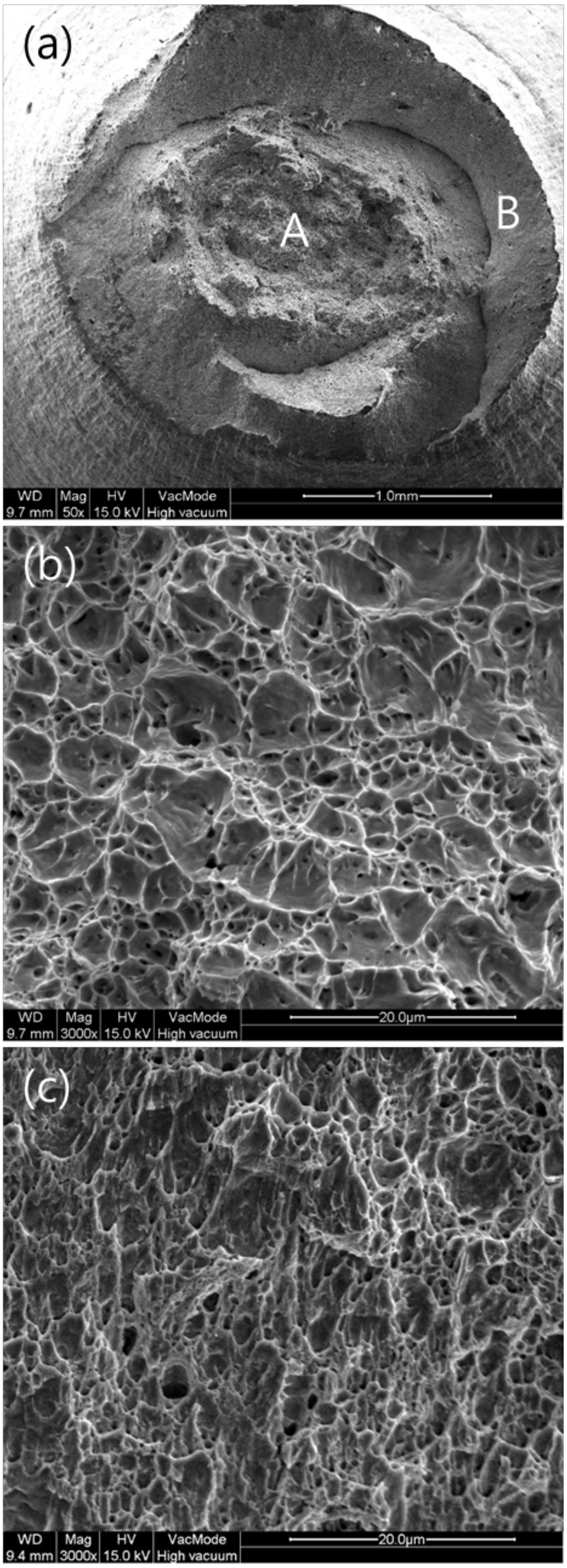

Fig. 2 Fracture surfaces of a specimen of API X70 tested in the air.

Fig. 1 shows hardness change of API X70 steel with hydrogen content.

Hardness of API X70 steel with the content of 1% hydrogen + 99% methane increased slightly compared with that of air (0% hydrogen), and then sustained its tendency up to 100% hydrogen. That is, the matrix hardening of API X70 steel was obtained by hydrogen penetration into the matrix of API X70 steel with performing the hydrogen gas condition under 10MPa gas pressure and then held 30 minute at room temperature.

3.2. Fracture surfaces of API X70 steel tested in the air

Fig. 2 shows SEM images of fracture surfaces in a tensile tested specimen of API X70 steel tested in the air. Fig. 2(a) shows the cup and cone type fracture. That is, the fracture behavior of a specimen of API X70 steel tested in the air shows typical ductile fracture mode.

Fig. 2(b) and (c) were enlarged fracture surfaces of the center part (marked as ‘A’) and sheared part (marked as ‘A’), respectively. No non-metallic inclusions were observed and many micro-voids were formed in both of Fig. 2(b) and (c). Both of inclusion and micro-void which formed in matrix of API X70 steel would be affect the hydrogen-induced cracking [5,8]. Equi-axed type dimples were observed at center part of fracture specimen as shown in Fig. 2(b), however, elongated and smaller size of dimples were formed at sheared part as shown in Fig. 2(c).

3.3. Fracture surfaces of API X70 steel tested in 100% hydrogen gas condition

Fig. 3 shows SEM images of fracture surfaces in a tensile tested specimen of API X-70 steel tested in 100% hydrogen gas.

Fig. 3(a) shows typical brittle fracture surface. The fracture surface shows flat and has many striations which mean crack propagation paths.

Fig. 3(b) and (c) were enlarged fracture surfaces of the center part (marked as ‘A’) and edge part (marked as ‘A’), respectively. Quasi-cleavage fracture surfaces were observed in Fig. 3(b) and (c). That is, typical brittle fracture mode was formed at 100% hydrogen gas condition. And secondary cracks were also observed in Fig. 3 (b) and (c) marked as arrow [4]. That is, crack propagated to the nominal direction of tensile direction.

Hydrogen-induced crack would be happen easily in presented API X70 steel because the micro-void would be play as a role of hydrogen nucleation site and trapped hydrogen [8]. Many of micro-voids were existed in matrix of API X70 steel tested in the air condition as shown in Fig. 2 [3,4,6,7]. From above results, hydrogen embrittlement was occurred at 100% hydrogen gas condition.

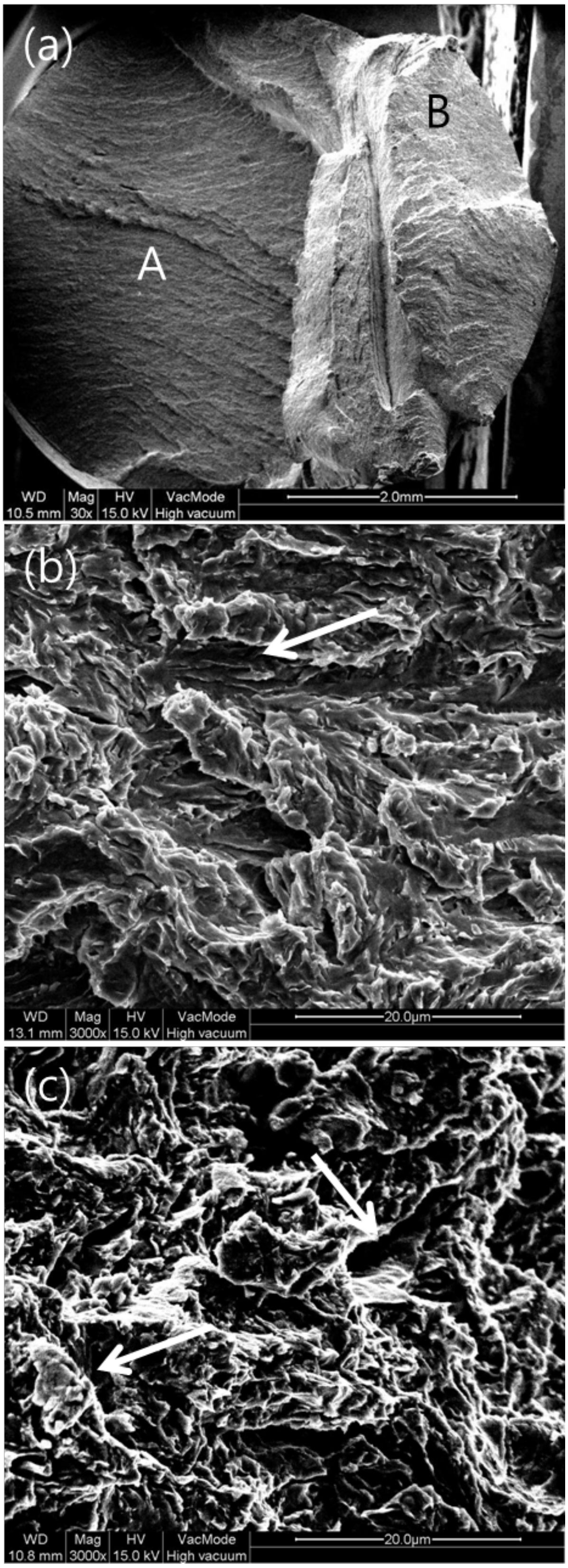

Fig. 3 Fracture surfaces of a specimen of API X70 steel tested in 100% Hydrogen.

3.4. External shapes of tensile specimens tested in the air and 100% hydrogen condition

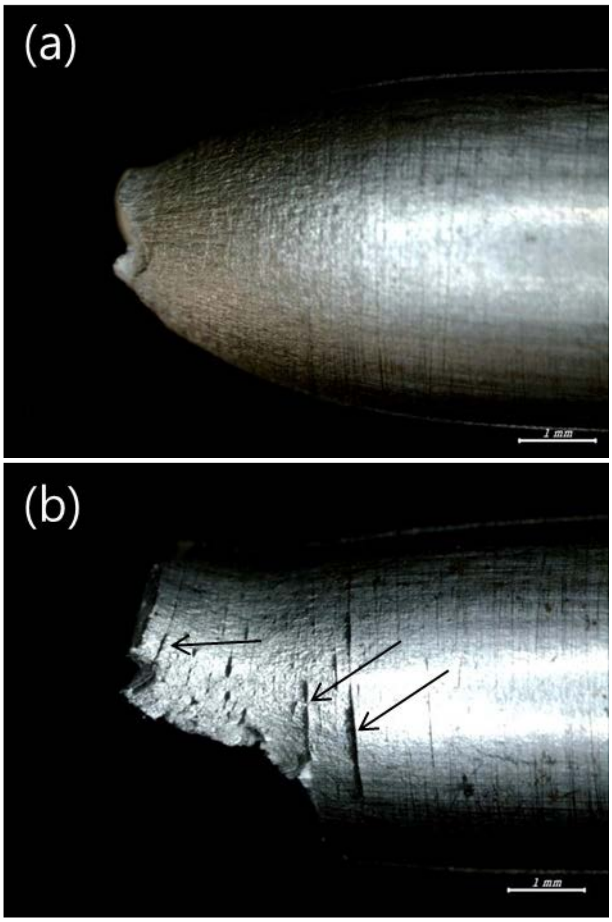

Fig. 4 External shapes of tensile specimens tested in (a) air and (b) 100% hydrogen.

Fig. 4 shows stereoscopic microscope photographs of external shapes of tensile specimens tested in (a) air and (b) 100% Hydrogen. Fig. 4(a) shows necked and ductile fractured area in gage length of tensile specimen tested in the air. Fig. 4(b) shows a little necked and brittle fractured area in gage length of tensile specimen tested in 100% hydrogen.

There's no circumferential crack was formed near ductile fractured surface as shown in Fig. 4(a), however, many circumferential cracks marked as arrows were observed near brittle fractured surface as shown in Fig. 4(b) [4].

From these results, ordinary ductile fractured surface was observed in API X70 steel specimen tested in the air condition but, many external cracks were formed simultaneously near necked area during tensile deformation in API X70 steel specimen in 100% hydrogen gas condition.

These several external cracks propagated simultaneously from the surface into the center direction of specimen and some of cracks encountered each other within the cross section of gage length, and then it divided into two brittle fractured surfaces as shown in Fig. 3(a) [5,6].

4. CONCLUSIONS

(1) Hardness of API X70 steel increased slightly with the content of hydrogen from the comparison of 0% hydrogen.

(2) No non-metallic inclusions were observed and many micro-voids were formed in the matrix of API X70 steel tested in the air condition.

(3) The fracture surfaces were changed from dimple type in the air to quasi-cleavage type with 100% hydrogen gas condition.

(4) External cracks were observed just only at 100% hydrogen content. No external crack were formed at the specimen surface of API X70 steel tensile tested in the air, however, many external cracks were observed at the specimen surface of that tested in 100% hydrogen gas condition.

ACKNOWLEGEMENT

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