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HYDROGEN EMBRITTLEMENT IN LOW CARBON STEEL

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ABSTRACT

Many metals and alloys absorb hydrogen and diffusion of hydrogen under certain conditions can seriously weaken and produces embrittlement in steel. Hydrogen embrittlement is a type of metal deterioration that is related to stress corrosion cracking. Although steels are well known for their susceptibility to hydrogen embrittlement, the mechanism of transportation of hydrogen is not very clear in low carbon steels. Standard tensile steel specimens were hydrogenated from 1 to 5 hours and deformed by cold worked to 50%,60%,70% 80% and were investigated for mechanical properties.

Keywords: Hydrogen embrittlement, tensile strength, yield strength, breaking strength, dislocation

1. INTRODUCTION

Stress corrosion cracking and hydrogen embrittlement cracking of welded weathering steel and carbon steel in a simulated acid rain environment was investigated by Choi and Kim [1]. The results indicated that weathering steel had better corrosion resistance than carbon steel. Hydrogen embrittlement in power plant steels was studied by Dayal and Parvathavarthini [2]. They found that in power plants, several major components such as steam generator tubes, boilers, steam/water pipe lines, water box of condensers were affected by hydrogen. A brief overview of current understanding of the phenomenon of such hydrogen damage in steels is presented. Case histories of failures are also briefly discussed. Carlos et.al. [3] studied the effects of hydrogen on carbon steels at the Multi-Function Waste Tank Facility. Concern has been expressed that hydrogen produced by corrosion, radiolysis, and decomposition of the waste could cause embrittlement of the carbon steel waste tanks at Hanford that might lead to catastrophic failure. Komazaki et.al. [4] investigated the changes in fracture and hydrogen evolution behaviors in Cu-added ultra low carbon steels due to hydrogen charging. Experimental results revealed that the higher strength steel bas a larger reduction in strength due to hydrogen charging and strongly dependent on the morphology of copper precipitation particles. Hydrogen embrittlement in 0.31% carbon steel used for petrochemical applications was reported by Abdullah and Siddiqui [5]. The investigation was carried out to assess the effect of hydrogenation time, independent of other processing and other constitutional variables, on the mechanical properties of 0.31% carbon steel. The results revealed that as the exposure time for cathodically charged hydrogenated steel was increased, an increase in tensile strength, yield strength and breaking strength was observed with a loss in ductility. SEM studies on the fractured surfaces of the hydrogen charged specimens exhibited surfaces ranging from intergranular tear to high-pressure fractured locations. Effect of the heat-affected zones on hydrogen permeation and embrittlement of low-carbon steels was investigated by Razzini et.al [6]. They found that the steels with yield strengths below about 900 MPa are essentially immune to hydrogen embrittlement, and almost all pipeline steels have a yield strength below that value. However, same catastrophic failures of pipelines have been reported

2. EXPERIMENTAL PROCEDURES

Steel pipe of 6 inch in diameter was brought from “Petroleum Development of Oman (PDO). The pipe was cut approximately 120 mm in length and 15 mm in width by milling machine. All the specimen of low carbon steel was annealed at 920 ± 5 °C for a period of half an hour. The specimens were cold worked by 50%, 60%, 70% and 80% by rolling mill at room temperature. The steel strips were further shaped into standard tensile specimens according to BSI specification by milling machine. The oxide layer from the steel specimen was removed by emery paper. All tensile specimens were painted or taped at the shoulder and cathodically hydrogenated with 200 ml of 0.1 M Na_2 SO_4 solution by passing a cathodic current through the working electrode. The specimens were charged with hydrogen for a period of 1 hour, 3 hrs, and 4 hrs, and 5 hrs. After charging of specimen with hydrogen, the specimens were immediately taken to measure that tensile strength yield strength, breaking strength and hardness of the hydrogenated specimens.

3. RESULTS AND DISCUSSION

3.1. Effect of cold work at constant hydrogenation time on low carbon steel

Standard tensile specimens were deformed by rolling to 50%, 60%, 70% and 80% at room temperature and hydrogenation for a constant period of 1,3, 4 and 5 hours. Fig.1 show the effect of cold work and hydrogenation on tensile strength of the low carbon steel. It is quite clear from the graph, as the cold work increases, there was an initial increase in tensile property of the low carbon steel when cold worked from 50% to 70% deformation. Further cold work to 80% deformed specimens has shown a small decrease in the tensile strength when hydrogenated for one hour. Other samples which were cold worked and hydrogenated at constant time of 3 hours, 4 hours and 5 hours showed a constant slow increase in tensile strength. Fig. 2 represent the effect of cold work at constant hydrogenation time on the yield strength. The experimental result indicates as the cold work increases from 50% to 80%, the yield strength of the low carbon steel decreases in one hour hydrogenated specimen. A similar trend was observed when the specimens were hydrogenated for a constant period of 3 hours ,4 hours and 5 hours and deformed to different percents. The effect of deformation on breaking strength is reported in Fig 3. The experimental results show as the percentage cold work increases, there is an initial increase in breaking property of the low carbon steel when cold worked for 50% to 70%. Further increase in cold work to 80% deformation has no affect on the breaking strength of the steel at constant hydrogenated time. Almost same effect was observed when low carbon steel was deformed and hydrogenated for 3 hours, 4 hours and 5 hours. The effect of deformation on hardness at constant period of hydrogenation time is reported in Figs. 4 and 8. A very small change in hardness was observed with increasing deformation or by increasing hydrogenation time.

3.2. Effect of hydrogenation time at constant cold work on low carbon steel

The effect of hydrogenation time on tensile strength at constant cold work in low carbon steel is represented in Fig. 5. It was quite clear from the graph that there was a decrease in tensile property of material when hydrogenation from 1 to 5 hours in 50 % cold worked specimens. A similar behavior was observed in 70% cold work specimens when hydrogenated for different intervals of time. The 60 % and 80 % cold worked steels showed an increase in tensile strength. The over-all trend was, longer hydrogenation time at constant deformation produces an increased the tensile strength in the low carbon steel. Fig. 6 represents the effect of hydrogenation time on the yield strength in low carbon steel. It is quite clear from the graph as the H-charging time increases from 1 hour to 5 hours the yield strength of the low carbon steel decreases. Similar behavior was observed in all other cold worked specimens when charged with hydrogen from 1 to 5 hours at different % of deformation. The effect of hydrogenation time on breaking strength is reported in Fig. 7. It is obvious from the graph as the hydrogen charging time increases from 1 to 5 hours the breaking strength decreases in 50% and 70% deformed specimens. An opposite behavior was observed in 60 % and 80 % deformed specimens. But the overall trend showed longer hydrogenation charging period has increased the breaking strength of the material. The mechanisms of hydrogen embrittlement are not clear yet. Several models try to explain the increase and decrease in mechanical properties of the hydrogenated materials but no theory could fully explain the reduction in the mechanical properties of the materials. Our experimental results show the effect of cold plastic deformation on the increase in strength of the low carbon steel is due to increase in dislocation density with increase in cold deformation.

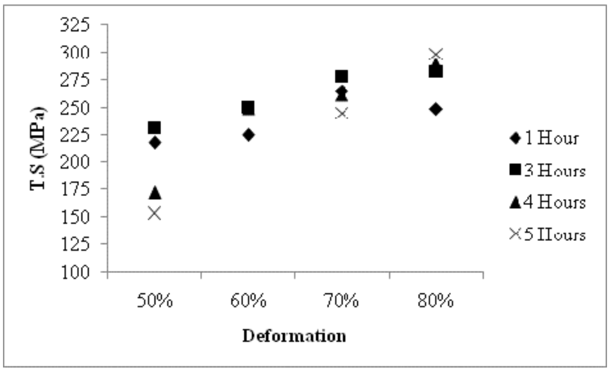

Figure 1. Effects of deformation on tensile strength.

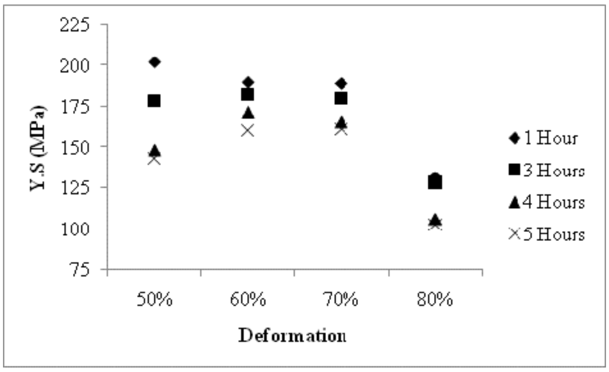

Figure 2. Effects of deformation on yield strength.

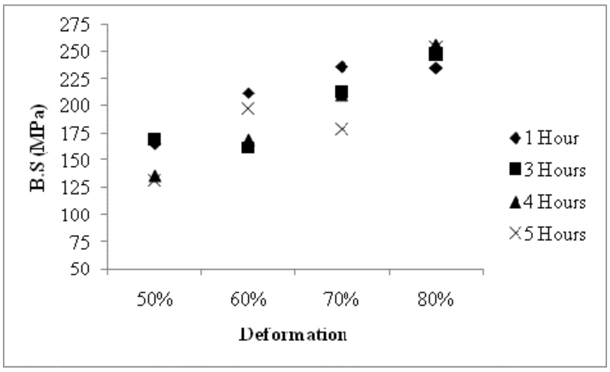

Figure 3. Effects of deformation on breaking strength.

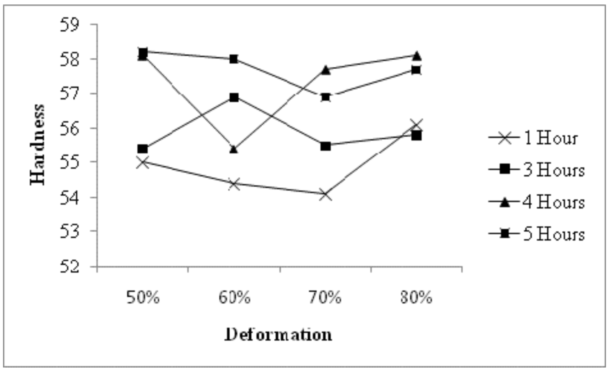

Figure 4. Effects of deformation on hardness.

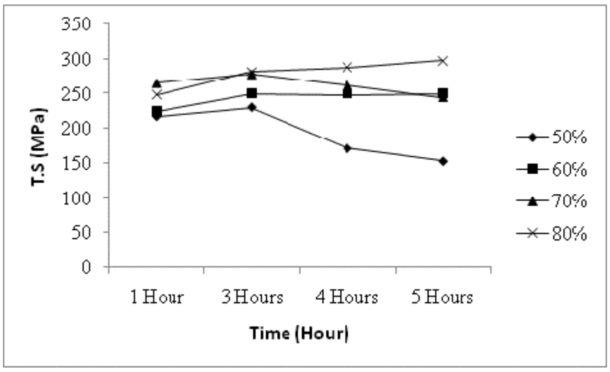

Figure 5. Effects of hydrogenation time on tensile strength of low carbon steel.

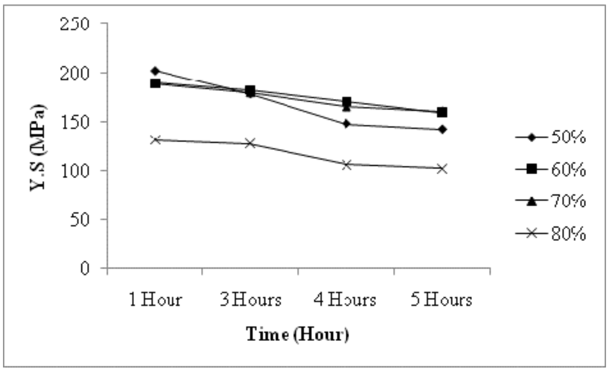

Figure 6. Effects of hydrogenation time on yield strength of low carbon steel.

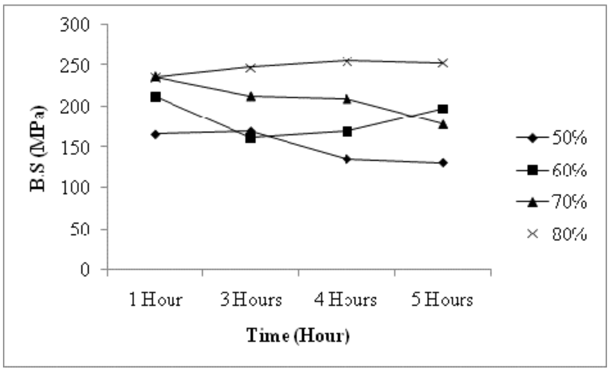

Figure 7. Effects of hydrogenation time on breaking strength of low carbon steel.

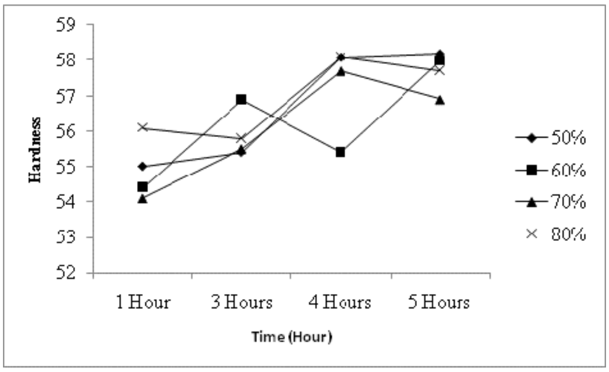

Figure 8. Effects of hydrogenation time on hardness of low carbon steel.

New dislocations are created by the cold deformation and they must interact with those already existing. As the dislocation density increases with deformation, it become more and more difficult for the dislocations to move through the existing forest of dislocations and this causes strain hardening in the material with increase in cold deformation. The reduction in the mechanical properties could also be explained is due to solid solution diffusion of hydrogen atoms into the lattices. They participate as gaseous hydrogen into pre-existing micro pores/voids. The fracture strength of the material was reduced due to pressure exerted by the gas adds to the external applied tensile load on the material and a decrease in mechanical property is observed. The trap theory of Pressouyres [7] explained, a crack is initiated or its growth is assisted, when the concentration of hydrogen trapped in pre-existing stressed defect exceeds some critical value. This causes embrittlement in material therefore the mechanical properties of material are affected.

4. CONCLUSIONS

It is concluded from the experimental results that as the % deformation increases, an increase in T.S of the material is observed. This could be due to dislocation produced during deformation process. These dislocations move along in certain slip place and can't go from one grain to other grain in a straight line. Since each grain has its own set of dislocation and own preferred slip plane, so they act as a barriers to dislocation movement and causes the dislocation to pile up at the grain boundary. As the percentage deformation increases, the density of dislocation also increases and it became more and more hard for dislocation to move through this forest of dislocation and thus causes an increase in strength of the material. The increase in strength with hydrogenation could also be explained is due to diffusion of hydrogen at the interstitial position, which produces a stress field around each solute atom. This stress field interacts with dislocation and makes their movement more difficult. Thus the solid solution becomes stronger than the pure metal. Therefore increases in tensile, yield, breaking strengths and hardness are observed in most of the cases. This increase in strength and hardness is not very high which can make this material brittle.

5. REFERENCES

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