EFFECT OF HYDROGEN EMBRITTLEMENT ON FATIGUE LIFE OF HIGH STRENGTH STEEL

Alok Kumar[1], Manish Vishwakarma[2]

[1]M.Tech. Scholar, [2]Assistant professor
Department of Mechanical Engineering,
Maulana Azad National Institute of Technology,
Bhopal 462003, Madhya Pradesh, India

***Abstract*: this paper deals with definition of hydrogen embrittlement, causes and mechanism which causes hydrogen diffusion take place in to the base material. Hydrogen embrittlement is responsible for subcritical crack growth and catastrophic failure in material. Hydrogen embrittlement causes due to high hydrogen concentration in the material. Different type of testing has been done to check the strength and properties of material. The microstructure analysis was done by scanning electron microscope (SEM) and transmission electron microscope (TEM)**

***Keywords*: High strength steel, Hydrogen embrittlement, SEM, TEM, subcritical crack growth**

1. Introduction:

Hydrogen embrittlement is a process by which steel become brittle and fracture due to subsequent diffusion of hydrogen in to the metal.

During hydrogen embrittlement hydrogen is reacted to the surface of a metal and individual hydrogen atoms diffuse through the metal, because the solubility of hydrogen increases with higher temperatures, high temperature can increase the diffusion of hydrogen. When facilitate by a concentration of hydrogen where there is significantly more hydrogen outside the metal, hydrogen diffusion can also occur at lower temperatures. These individual hydrogen atoms within the metal gradually mixes to form hydrogen molecules, creating pressure from within the metal. This pressure may increases the levels where the metal has reduced ductility, toughness, and tensile strength, up to the point where it cracks initiated. Hydrogen embrittlement occur during various manufacturing operations. During operation when metal comes into contact with atomic hydrogen.Various Processes lead cathodic reaction, phosphating and electroplating. A special case is arc welding, in which the hydrogen is released from moisture, such as in the coating of welding electrodes.

1.1 Sources of Hydrogen embrittlement:

The Sources of hydrogen causing embrittlement have been concurrence in the making of steel, in processing parts, in welding, in storage tank or containment of hydrogen gas. Hydrogen embrittlement mainly occur in nuclear industry. Hydrogen can be produced by corrosion reactions such as rusting, cathodic reaction, and electroplating. Hydrogen can also be added in reactor coolant to remove oxygen from coolant systems.

2. Literature Review:

In High strength steels, HE failure is initiated by crack nucleation and subcritical crack growth. In other HE cases, the mechanical strength is reduced and ductility is significantly affected.(e.g. charging condition, and loading condition) [1]. The degradation of mechanical properties of high strength steel is a combined effect of hydrogen embrittlement, changes in material composition, grain size and phase composition [2]. The desorption behavior of hydrogen has been analyzed during diffusion process of tensile testing, constant stress testing and fatigue testing using a tempered martensitic steel is examples of high strength steels [3]. A coexistent of Hydrogen embrittlement mechanisms Of Hydrogen enhanced localized plasticity and Hydrogen enhanced decohesion (HELP+HEDE) is distinguish by a mixed, quasi-cleavage mode of fracture, and their Simultaneous effect is mainly responsible for reducing ductility [4]. The effect of pre-strain on hydrogen embrittlement of high strength steel was investigated by SEM fractographs it stats that the fracture surface shows a mixed mode of quasi cleavage and intergranular fracture for hydrogen-charged samples [5]. The interaction between the strength of the material and the degree of hydrogen embrittlement was confirmed, except for the High strength low alloy steel where secondary effects presence of carbides played a vital role [6]. The diffused hydrogen in iron lattice decreases the strain at fracture of the high strength steel, but yield stress and the ultimate stress have not changed [7]. The effect of hydrogen on fatigue crack growth rates (FCGR) was analyzed through increasing and decreasing Stress Intensity factor (del k) tests [8]. The effect of pressure surge on the development of cracks decreases with time and the later in time a pressure surge occurs the less effective it is in causing pipe wall failure [9]. The cyclic prestress increases the hydrogen concentration and the size of vacancies that are more thermally stable than other stresses [10]. Fatigue crack growth within a tinny α martensite layer was mainly responsible for the Fatigue crack growth rate of the specimens in hydrogen [11]. When samples are charged with hydrogen the crack growth rate increases rapidly, up to two orders of magnitude in the range of physical parameters analyzed in our tests. At the same Del K value, da/dN increases when the temperature increases or the frequency decreases [12]. Fatigue crack growth rates increases in the presence of hydrogen atom and this is dependent on cyclic load frequency. The dependency on load frequency is outcome of the very low hydrogen concentration. It is concluded that hydrogen fatigue-resisting carbon steel completely prevent the hydrogen induced fatigue crack growth in the material acceleration can be produced by adding carbide-forming elements and refining ferrite crystal grains. [13]. the effect of hydrogen was found to be more at lower ΔK and lower stress ratios [14]. During the straining of 304L SS at 25 degree in H_2, the premature cracking of the α′-martensite in the small deformation zone preceding of the crack tip led to the high HE susceptibility of the specimen [15]. The present study highlight on the mechanism of intergranular fracture in terms of the microscopic deformation structures near the crack propagation paths. It has been found that the IG fracture is assign to hydrogen-enhanced dislocation structure development and subsequent micro void formation along the grain boundaries [16]. It has been concluded that hydrogen fatigue resisting carbon steel that may completely prevent the hydrogen induced fatigue crack growth acceleration can be produced by adding carbide-forming elements and refining ferrite crystal grains [17]. The fracture toughness of the base material under cathodic reaction was dependent on the direction of crack propagation the lower aspect ratio, and this phase crack propagation is decreased which we found lower toughness [18]

3. Methodology:

During Investigation of effect of hydrogen embrittlement on fatigue life of high strength Steel. We use different experimental methods.

1. **Method of Hydrogen Charging:-**

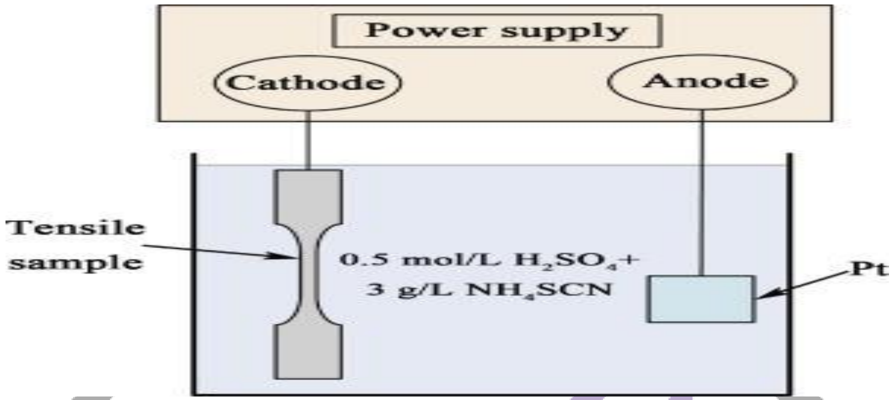

Fig 1. Schematic Diagram of Hydrogen Charging.

Hydrogen was charged in to the specimens of high strength steel by saturated them in ammonium thiocyanate and H2S04 solution, Hydrogen charging in to the specimens of high strength steel was

Performed either by cathodic charging or by exposure to high pressure hydrogen gas (63 MPa).

2. Method of Tensile testing:-

Tensile testing is a fundamental mechanical test used to determine the young's modulus and other tensile properties like:- ultimate tensile stress, yield tensile stress and percentage of elongation. Tensile testing is also used to determine the maximum load (tensile strength) that a material or a product can withstand.

3. Method of fatigue testing :- Fatigue test of the hydrogen - charged and uncharged specimen were performed at room temperature in laboratory air, the fatigue test for high strength steel were conducted at a high stress ratio R=-1 and a testing frequency between 0.02 Hz & 20 Hz Fatigue tests at very low frequency were carried out to investigate the effects of hydrogen and test frequency on fatigue crack growth

4. Fracture Analysis:- SEM is used to check the fracture in specimen, the fracture surfaces were cut to an appropriate size for scanning electron microscope examination.

4. Conclusion:

Due to hydrogen embrittlement Mechanical properties (Strength and ductility) of high strength steel material was reduced. Microstructural examination of fractured samples will be done to determine the effect of hydrogen on fracture behavior and subcritical crack growth of fractured samples. As seen from results that mechanical properties get decreased with the effect of hydrogen during tensile testing. Further work will be carried for fatigue testing and SEM examination of the fractured sample to know the microstructural changes in material due to the effect of hydrogen.

References

[1] Jeffrey Venezuela, et.al,A review of hydrogen embrittlement of martensitic advanced high-strength steels, 26 April 2016 (153-186)

[2] Le Li, Mojtaba, et.al, Effect of corrosion and hydrogen embrittlement on microstructure and mechanical properties of mild steel, ConstructioN and Building Materials, volume 170, (2018) 78–90

[3] Yu Matsumoto, et.al, Hydrogen behavior in high strength steels during various stress applications corresponding to Different hydrogen embrittlement testing methods, Material science & Engineering, Volume 735 (2018) 61-72

[4] M. B. Djukic, et.al, Hydrogen embrittlement of low carbon structural steel, Procedia Materials science, Volume 3 (2014) 1167-1172

[5] Xinfeng Li, et.al, Effect of pre-strain on hydrogen embrittlement of high strength steels , Material science & Engineering volume 616, 20oct (2014)

[6] T. Depover, et.al, Effect of hydrogen charging on the mechanical properties of advanced high strength steels , International Journal ofHydrogen energy, volume 39, 18 March (2014)

[7] J. Sanchez, et.al, Measurement of hydrogen and embrittlement of high strength steels, Engineering Failure Analysis, volume 59, jan(2016) 467-477

[8] A. Roy, et.al, Anomalies in hydrogen enhanced fatigue of a high strength steel, Interanational Journal of Fatigue, Volume 59 Feb(2014) 14-22

[9] Ali Rajabipour, et.al, Service life of corrosion pitted pipes subject to fatigue loading and hydrogen embrittlement, International Journal of Hydrogen energy, volume 43 (2018) 8440-8450

[10] Seok Weon Song, et.al, Effects of carbon content on the tensile and fatigue properties in hydrogen charged Fe-17Mn-xC steels, Material Science & Engineering, volume 724 (2018) 469-476

[11] Jeffrey Venezuela, et.al, The influence of microstructure on the hydrogen embrittlement susceptibility of martensitic advanced high strength steels, Material today communications, volume 17 (2018) 1-14

[12] L. Briottet, et.al, Fatigue crack initiation and growth in a CrMo steel under hydrogen pressure, International Journal of Hydrogen energy, Volume 40 (2015) 17021-17030

[13] Motomichi Koyama, et.al, Overview of hydrogen embrittlement in high-Mn steels, International Journal of Hydrogen energy, Volume 42 (2017) 12706-12723

[14] T. Doshida, et.al, Hydrogen-enhanced lattice defect formation and hydrogen embrittlement of cyclically prestressed tempered martensite steel, Volume 61 (2013) 7755-7766

[15] T.C. Chen et.al, The effect of phase transformation in the plastic zone on the hydrogen assisted fatigue crack growth of 301 stainless steel, Material characterization, Volume 112 (2016) 134-141

[16] P. Fassina et.al, Effect of hydrogen and low temperature on fatigue crack growth of pipeline steels , Engineering Fracture Mechanics, Volume 103 (2013) 10-25

[17] Yukitaka Murakami et.al, Effect of hydrogen on fatigue crack growth of metals, Engineering Fracture Mechanics, Volume 77 (2010) 1926-1940

[18] Arijit Roy et.al, Hydrogen enhanced fatigue crack growth in an HSLA steel, Material science& Engineering, Volume 588 (2013) 86-96

[19] C.L. Lai et.al, Effect of microstructure on hydrogen embrittlement of various stainless steels, Material science & Engineering, Volume 584 (2013) 14-20

[20] Yuhei Ogawa, et.al, The role of intergranular fracture on hydrogen-assisted fatigue crack propagation in pure iron at a low stress intensity range, Material science & Engineering, (2018)

[21] Masao Hayakawa, et.al, Hydrogen fatigue-resisting carbon steels, Procedia Material science, Volume 3 (2014) 2011-2015