Slow Strain Rate Testing to Evaluate the Susceptibility of Welded Low Alloy Steel to Environmentally Assisted Cracking

Fathi M. Abusaa

***Abstract* — Libya is an important oil country particularly to European countries. The combustion products of fossil fuels are causing great damage through pollution, acid rains and the greenhouse effect. Hydrogen can be stored in three different ways, as a gas, as liquid, as a material and metal hydrides. Low alloy steels have been widely used in different scale welded structures. The mechanical properties were determined with the slow strain rate test in air and in artificial seawater environment under cathodic polarization to produced hydrogen. The slight decrease in fracture energy and reduction in area at current densities in artificial seawater in comparison with the values measured in air were observed.**

***Index Terms* — hydrogen storage, low alloy steel, welded steel, slow strain rate test (SSRT).**

I. INTRODUCTION

Libya is located in the middle of North Africa with 88% of its area considered to be desert areas. The main sources of energy in Libya are Oil and natural gas, which meet most of the energy demand today, are being depleted fast. The total energy demand has increased from 5.4 Mte in 1990 to 9.1 Mte in 2003 with growth of 60 %. Primary studies shows that the Future Energy demand in 2010 will be 11.5 Mte as shown in figure 1 [1].

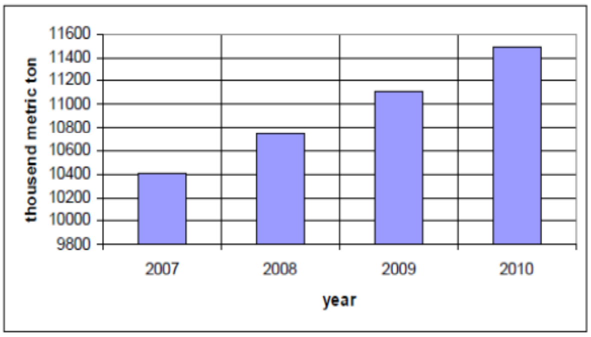

Fig. 1. Forecasting energy demand [1].

Libya emitted more than 50 million tons of CO2 in 2002 that is about 0.2% of world carbon dioxide emissions.
Most of CO_2 emissions come from fuel combustion in the power generation sector (38%), in the transport sector (20%) and in industry (8%). Other sectors represent 34%.

Faculty of Engineering, Misurata University ,Libya
e-mail: fathi_abusaa@hotmail.com

Eljrushi, and Vezeroglu developed a model for solar hydrogen energy system for Libya by obtaining relationships for and between the main energy and energy related parameters. The following variables have been chosen to construct the model: population, energy-demand, energy production, energy price, gross national product, air pollution and quality of life [2].
Hydrogen allows for the storage of the energy produced during one season to be used in another. It gives home power producers the option of eliminating the last of their fossil fuels. The large-scale production of hydrogen could result in a large-scale reduction in the use of petroleum fuels by the year 2050 [3].
Hydrogen storage by hydrides have many advantages over liquid & gas. Hydrogen storage in solids may make it possible to store larger quantities of hydrogen in smaller volumes at low pressure and at temperatures close to room temperature. It is also possible to achieve volumetric storage densities greater than liquid hydrogen because the hydrogen molecule is dissociated into atomic hydrogen within the metal hydride lattice structure.
Abdellatif Miraoui proposed a hybrid system for street lighting coupling PV, battery and fuel cell in order to improve the classical system coupling, PV and battery, which cannot work all the year. A simulation model is used to evaluate the validity of the different hybrid configurations; an optimal configuration is obtained and shows that a 60w street light system would costs 7150 euro with a lifetime of 25 years [4].
Low-alloy steels are designed to provide better mechanical properties and/or greater resistance to atmospheric corrosion than conventional carbon steels in the normal sense because they are designed to meet specific mechanical properties rather than a chemical composition.
Low alloy steels have minimum yield strength ranging from 420 to 690 MPa, good toughness, and weld ability. Steels are produced as: quenched and tempered, TMCP (Thermo Mechanical Control Process) and precipitation hardened [5]. Significant limitation of use of high strength steels could be their hydrogen degradation. Hydrogen degradation is a persistent concern affecting the use of a broad range of ferrous and non-ferrous structural materials exposed to marine environments [6]. The term of hydrogen degradation is used to characterize the near room temperature effects of hydrogen on materials. The susceptibility of weldable low alloy steels to hydrogen degradation is generally considered to be directly proportional to yield strength (i.e. susceptibility increases with increasing yield strength) for a given alloy class, the need to characterize the performance of these steels and their associated welding systems is critical [7]. The diffusible hydrogen content in steel weldment could led to a cracking phenomenon known as, hydrogen assisted cracking, cold cracking

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or delayed cracking [8]. Woodward and Cottis reported a considerably lower degradation ratio, i.e. a greater ductility loss, for the grain coarse HAZ than for the base metal [9]. Degradation in the HAZ has been generally observed to occur next to the fusion line, and attributed to the formation of low toughness transformation product. Hydrogen was found not only in the host lattice, but also segregated to atomic and micro structural defects such as vacancies, dislocations, grain boundaries, micro voids, and second-phase particles.

Steels could be charged with hydrogen in vicinity of polarization anodes, over-protection, or by presence of some sulfate-reducing bacteria in sea-water . Additionally, welded joints contain some amount of hydrogen introduced into a material during welding. This could increase a risk of hydrogen degradation during service.

The aim of this work is to evaluate hydrogen degradation of low alloy steel grade E690 welded joints made by (SAW) under cathodic polarization (hydrogen uptake).

II. Experimental and results

A quenched and tempered plate 12 mm in thickness made of E690 steel grade evaluated. The chemical composition of the tested steel is given in table 1.

Table I
CHEMICAL COMPOSITION OF THE TESTD STEEL GRADE E690

Elements content, wt.%, according to the chemical analysis			
C	0.13	Ni	0.74
Si	0.12	Mo	0.40
Mn	0.83	Cu	0.25
P	0.001	Ti	0.004
S	0.005	V	0.05
Cr	0.43	Al	0.02
B	0.002		

Welding processes were carried out according to the ANSI/AWS
specification A5.1. Welded specimens were prepared by (SAW) techniques.

The expected heat affected zone HAZ properties did not recommend preheating and post-heating treatments. X-ray diffraction techniques were used to observe welding defects might occur in welded joints for welding processes. Samples prepared from base metal after welding were cut transverse to the welding direction and perpendicular to the rolling direction and machined in order to obtain again the round smooth specimens. There was no difference between specimens used for determining the mechanical properties and those for slow strain rate tests. The results of mechanical properties of welded joints are presented in table 2.

Table II
MECHANICAL PROPERTIES OF BASE AND WELDED JOINTS E690 MADE BY SAW

Base Metal E690		Welded Material by SAW	
Tensile Strength MPa (RM)	869	Tensile Strength MPa (RM)	706
Yeild Strength MPa	798	Yeild Strength MPa	530
Elongation Ao %	11.1	Elongation Ao %	10.7
Reduction Area Zo %	59.4	Reduction Area Zo %	59.4

Hardness distribution in the welded joint was measured on a cross-section with the Vickers method using 98.07 N load. The hardness values of welded zone obtained with either SAW techniques used as an indicator of susceptibility to hydrogen gradation (HE) when detecting the maximum and minimum hardness values: the zone possessing higher hardness may be more susceptible to hydrogen degradation than zone of lower hardness value.

The maximum hardness values measured on welded joints made by SAW ranged from 251 HV to 210 HV, where in base metal was 205HV, (fig.2).

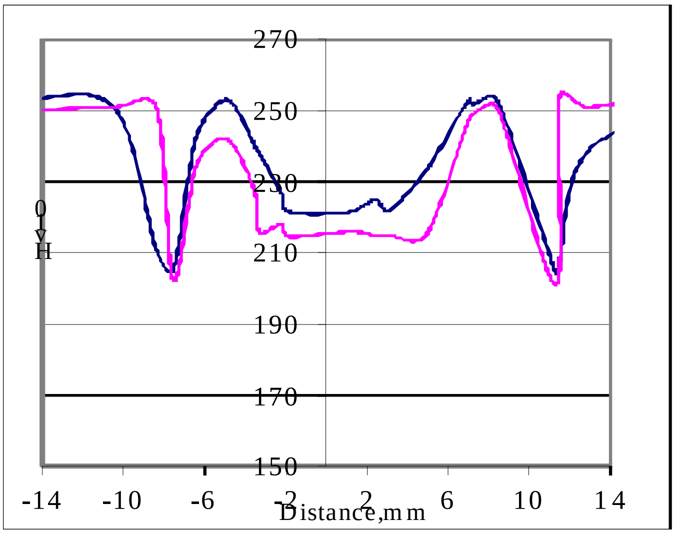

Fig. 2. The distribution of hardness values for SAW

In order to estimate degree of hydrogen degradation of welded joints, slow strain rate test (SSRT) according to ASTM G 129-95 [11], was conducted on round smooth specimens 4 mm in diameter and the gage length was 50 mm. Specimens were cut along the transverse direction.

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Tests were performed at ambient temperature either in dry air or standard artificial sea-water according to ASTM 4111, the applied strain rate was 10^{-6} (s^{-1})

Tests in sea-water were conducted under cathodic polarization (hydrogen uptake) constant cathodic current values chosen from the polarization curve. The following cathodic currents were applied: 0,0.1, 1, 10, 20 and 50 mA/cm^2. As the degree of hydrogen degradation index the relative values of: fracture energy (Ef/Eo), reduction in area (Zf/Zo) and tensile strength (Rf/Ro) were determined as the ratios of appropriate properties measured in artificial sea-water to these measured in air (fig.3,4).

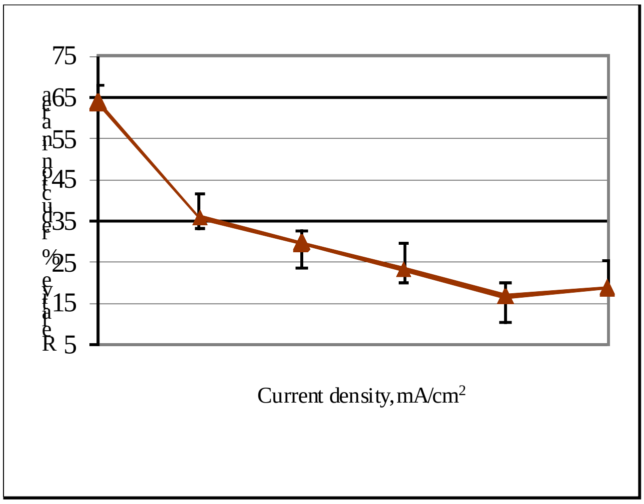

Fig. 3. Relative reduction in area Zf/Zo (degradation index) versus cathodic current density (H uptake) for SAW in artificial sea-water.

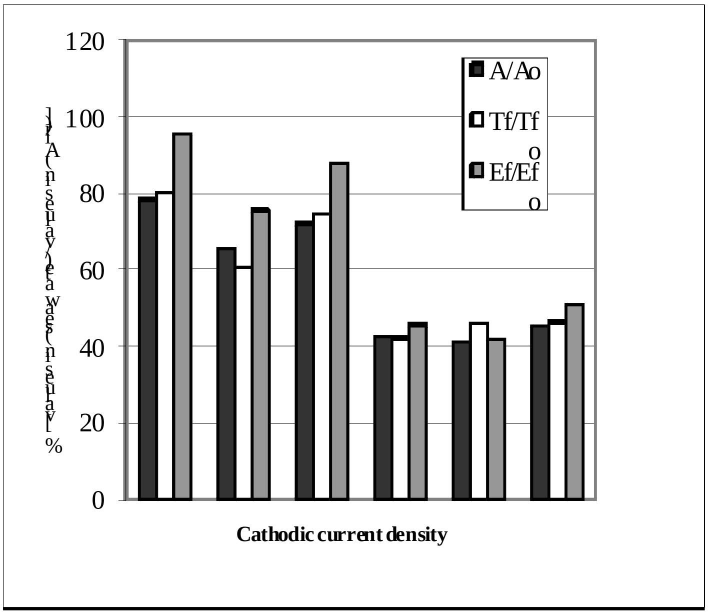

Fig. 4. Relative values of elongation (Af/Ao),time to failure (Tf/To) and fracture energy (Ef/Eo) versus cathodic current density(H uptake) for SAW.

III. Discussion

The susceptibility of welded high strength low alloy steels to hydrogen degradation dependent on the applied current polarization, should be taken into account at the design stage as part of the material selection process, as should the design of the cathodic protection(H up take). It was therefore felt necessary to study the hydrogen degrading (H uptake) behavior of the steel grade E690 and its welded joint condition using the SSRT technique under a wide range of applied cathodic polarization (H up take).

Combining the cathodic protection levels measured on site and SSRT testing data from tests, it is evident that a level of cathodic protection should be focused upon where hydrogen damage is minimized and protection afforded. The most important factor is the percentage of reduction in area which is known to have a direct influence on hydrogen degradation. The relative values (degrading indexes) represented by reduction in area may be considered as the degrading index increases, a change in reduction in area decreased, with current densities increased, similar results were obtained by [12]. As shown in figure 4, the welded joints tested in artificial seawater under cathodic polarization exhibited loss of ductility 21% at 20 mA/cm^2.

The present study further reveals that hydrogen degradation of welded joints made by SAW technique of different strength can lead to the hazard of hydrogen degrading. The degradation is not very strong, but depends on the degree of cathodic current density application. It was shown that conditions causing penetration of hydrogen occur in practice; the first and most probable source of a large hydrogen quantity is the cathodic protection (H up take), the, second less essential, is other factor like the method of welding joints.

Less sensitive was other parameter, fracture energy, which in extreme cases decreased to 42-85% of reference value (fig.4). The increased hydrogen degrading susceptibility in the HAZ of welds is a result of the microstructure changes that occur during the thermal cycle.

The susceptibility of welded low alloy steels to hydrogen degrading (H up take) depends on the applied cathodic polarization and should be taken into account at the design stage as part of the material selection process or design of the cathodic protection. The danger of hydrogen degrading of welded joints exists, however, if as a criterion will be considered the fracture energy or reduction in area. On the other hand, the used SSRT test creates sharper conditions than met in practice.

IV. Conclusions

A. Mechanical properties of welded joints by SAW at slow strain rate test in artificial seawater under hydrogen up take (hydrogen storage by metal hydride) were decreased.

B. A decrease is observes for reduction in area and fracture energy, while tensil3q e strength is at constant level, so it is evidence of hydrogen degradation (hydrogen up take).

C. Application of welded E690 in hydrogen storage (metal hydride) could be associated with a risk of brittle cracking.

References

[1] Abdullah Ballut, Mohamed Ekhlat "The Potential Impact Of Improved Energy,utilization Efficiency On The Future Energy Demand In Libya Up To The Year 2020" 17th World Energy Congress, USA ,1998.

[2] G. Eljrushi, T. Veziroglu, Solar-Hydrogen System for Libya. International Journal of hydrogen Energy, 15(12), 1990, P. 885-891.

[3] Paul Kruger, Appropriate technologies for long-scale production of electricity and hydrogen, International Journal of Hydrogen Energy, 33, 2008, P. 5881-5886.

[4] Abdellatif Miraau, Sizing optimization of standalone street lightening system powered by a hybrid system using fuel cell, PV and battery. Renewable Energy, 34, 2008, P. 683-691.

[5] D.A. Davis and D.M. Aylor.Stress Corrosion Cracking of Naval Structural Steels., DTRC-SME-90/17 May 1990.

[6] H. Asahi,. and Sogo.Y. Metallurgical factors controlling SCC resistance of high strength low alloy steels, 1989, Vol.45, No.6, pp.519-526.

[8] Raymond R.:The effect of welding parameters on diffusiblehydrogen content in steel weldments,. Feb.25/2000,Welding Engineering literature reviews.

[9] Woodward.J and Cottis.R.: Hydrogen transport and cracking in metals., Edt. Turnbull.A., Report; The institute of Materials., 1995,London.UK.,pp.253-267.

[10] K.Banerjee and U.K.Chartterjee.: Effect of applied potential on hydrogen embrittlement of weld simulatde HSLA-80 steel in sea water, British corrosion J. 2000,Vol.35/No.4,pp.273-278.

[11] ASTM, ASTM G 129-95. Slow strain rate testing to evaluate the susceptibility of metallic materials to environmentally assisted cracking, 1996.

[12] Domzalicki,.P, Zielinski. A and Lunarska.E.:Effect of hydrogen on SCC and CF of the HSLA steels in seawater., Int.Conf. Engineering materials environmental degradation. Vol.I, pp.125-130.,Gdansk-Poland,19-23 Sept.1999.

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