Experimental study of effects of hydrogen embrittlement and residual stress on mechanical properties of GTD450

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ABSTRACT

The subject of the present paper is the experimental study of the effects of hydrogen embrittlement with residual stress on the mechanical properties of GTD450 alloy. Hence, 0.5 M sulfuric acid was used to create one- and two-hour hydrogen charging, and the cylindrical-toothed method was used to generate residual stress. Based on experimental findings, changes in flexibility and percentage of reduction of failure area, compared to the baseline conditions ranged from 42.69% to 74.68% and 11.78% to 39.58%, respectively. The results of statistical analysis have estimated the contribution of residual stress and hydrogen embrittlement to flexibility as 1.15% and 67.05%, respectively. For the residual stress related to the five kN force, by increasing the hydrogen charging to two hours, the toughness value decreases by 60.54%. It was also observed that the maximum change in yield stress is 1.68%, which is caused in the sample by one-hour hydrogen embrittlement and residual stress due to a force of nine kN. In the baseline case, the necking was collapsed with high strain and the area of failure was reduced by 36%; however, under two-hour charging, failure occurred with a minimum of necking, low strain and slight reduction of failure area by 21.75%.

KEYWORDS

Hydrogen embrittlement, residual stress, mechanical properties, tensile test, GTD450 steel.

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1. Introduction

Corrosion in turbines and compressors is usually caused by the presence of moisture and salts. In corrosive solutions, hydrogen is released during the electrochemical reaction and hydrogen embrittlement is created by the penetration of hydrogen into the metal. Jang et al. [1] studied hydrogen embrittlement and hydrogen-based failure. They investigated the electrochemical behavior of the hydrogen charge of the AL8090 alloy in samples with different orientations. The results show that hydrogen charging reduces the flexibility and fracture toughness of the AL8090. Lu et al. [2] showed that atomic vacancies can combine with hydrogen and play a key role in hydrogen embrittlement in flexible solids. Lee et al. [3] provided a comprehensive analysis of the growth rate of stress corrosion cracking.

In the present paper, GTD450 alloy, as a martensitic stainless steel with high-strength and relatively high-corrosion-resistant, is subjected to cracking with internal hydrogen embrittlement . In addition to hydrogen embrittlement , the standard samples were subjected to residual stress by the indentation method. After creating residual stress, the samples were subjected to hydrogen charge and then tensile test was performed on them. Accordingly, changes in mechanical properties of the sample including yield stress, ultimate stress, flexibility and reduced cross-sectional area of failure and toughness, in terms of residual stress and hydrogen embrittlement have been reported.

2. Sample selection and preparation

The standard samples of the tensile test prepared in this research are made of AISI Custom450 steel. The standard sample for tensile testing is the Subsize Specimen flat type, based on the ASTM E8 standard [4]. The dimensions of the selected sample are given in Fig. 1 in millimeters.

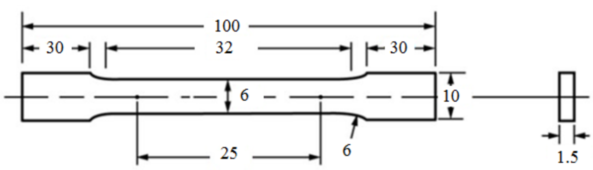

Fig. 1 A schematic of Standard sample of tensile test.

Mechanical polishing method was used to prepare the surface. On each sample, three indentations were made, one in the middle and two on the sides at a distance of 5 mm from the center. Residual stresses resulting from this indentation have been applied to the samples at two levels of 5 kN and 9 kN at a speed of 0.5 mm/min. In order to apply hydrogen embrittlement , electrochemical method was used to pre-charge the samples in 0.5 M sulfuric acid (H2SO4) solution at ambient temperature.

3. Basics of statistical analysis and definition of parameters

In this paper, the contribution P of the two parameters of hydrogen embrittlement and residual stress on the each of dependent variables including yield stress, ultimate stress, flexibility, area of failure cross section and toughness, is reported. For this purpose, suppose PH, R is the contribution of hydrogen embrittlement and Pres, R is the contribution of residual stress participation to the arbitrary dependent variable R. Equations (1) and (2) are used to calculate the contribution of PH,R, and Pres,R[5] , respectively.

$$P_{H,R} = \frac{S_{H,R}}{S_{T,R}} \times 100 \quad (1)$$

$$P_{res,R} = \frac{S_{res,R}}{S_{T,R}} \times 100 \quad (2)$$

In Eq. (1) and (2), SH,R and Sres,R are the total variance of the hydrogen embrittlement and the residual stress, respectively, for the arbitrary variable R. Reference [5] has been used to calculate the values of SH and Sres. The flexibility L, area of failure cross section A and toughness UT are given in Eq. (3), (4) and (5), respectively.

$$L = \frac{l_f - l_0}{l_0} \quad (3)$$

$$A = \frac{A_0 - A_f}{A_0} \quad (4)$$

$$U_T = \int \sigma d\varepsilon \quad (5)$$

where l, A, σ and ε are the sample length, cross section area of sample, stress and strain, respectively. Also, in order to calculate the percentage of difference between each parameter and the corresponding value in the base state e, the difference in the value of each parameter with the corresponding value in the base state d, standard deviation S and mean standard error Se, Eqs. (6) to (9) are used, respectively.

$$e = \frac{\bar{R} - \bar{R}_b}{\bar{R}_b} \times 100 \quad (6)$$

$$d = \bar{R} - \bar{R}_b \quad (7)$$

$$S = \sqrt{\sum_{i=1}^{N} \left(R_i - \bar{R}\right)^2 / (N - 1)} \quad (8)$$

$$S_e = \frac{S}{\sqrt{N}} \quad (9)$$

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In Eqs. (6) to (9) the mean value of the parameter $\bar{R}$ is calculated after N repetition. Also $\bar{R}_b$ is the average value of the quantity R in the base condition.

4. Results and discussion

The term Iq-Cm-Nn is used to facilitate the naming of experiments. In this naming method, the letter q indicates the amount of force (kN), the letter m indicates the time (hours) of hydrogen charge, and the letter n indicates the number of experiment repetition. Table 1 reports the amount of yield stress for the baseline mode for 3 repetition and its average value. According to this table, the average value of yield stress for the baseline is 1086.06 MPa with 13.33 standard deviation and 7.70 standard error. Also, table 2 shows the yield stress values per repetition $\sigma_{y,i}$, the mean yield stress $\bar{\sigma}$, the percentage of difference between the mean value and the mean value of the baseline e%, the difference between the mean value and the mean value of the base state d, the standard deviation S and the standard mean error Se for four experiments of I5-C1, I5-C2, I9-C1 and I9-C2.

Table 1. The values of yield stress (MPa) in each repetition $\sigma_{y,i}$, the mean value of yield stress $\bar{\sigma}_y$, the standard deviation S and the mean standard error of S_e in the baseline experiment.

Experiment: I0-C0					
$\sigma_{y,1}$	$\sigma_{y,2}$	$\sigma_{y,3}$	$\bar{\sigma}_y$	S	S_e
1089.11	1097.6	1071.47	1086.06	13.33	7.7

5. Conclusion

1- By comparing the mean values of yield stress and ultimate stress at four levels I5(C1, C2), I9(C1, C2) with the mean values in the baseline, no significant difference is observed.

2- The results also show that with increasing charging time from one hour to two hours, the average amount of flexibility decreases to 4.15%. Also, the share of residual stress contribution in flexibility is equal to 1.15% and the share of hydrogen embrittlement contribution is equal to 67.05%.

3- The results show that increasing embrittlement reduces the toughness of the sample; thus, in I5C1 and I5-C2 conditions, the average toughness was calculated to be 103.5 J/cm3 and 40.84 J/cm3, respectively.

6. References

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Table 2. The values of yield stress (MPa) in each repetition $\sigma_{y,i}$, the mean value of yield stress $\bar{\sigma}_y$, the percentage difference between the mean value and the base state e%, the standard deviation S the difference between the mean value and the base state d and the mean standard error S_e in four experiments I5-C1, I5 -C2, I9-C1 and I9-C2.

Experiment: I5-C1							
$\sigma_{y,1}$	$\sigma_{y,2}$	$\sigma_{y,3}$	$\bar{\sigma}_y$	e%	d	S	S_e
1067.15	1122.7	1038.59	1076.15	-0.91	-9.91	42.77	24.69
Experiment: I5-C2							
$\sigma_{y,1}$	$\sigma_{y,2}$	$\sigma_{y,3}$	$\bar{\sigma}_y$	e%	d	S	S_e
1027.8	1076.43	1104.48	1069.57	-1.52	-16.49	38.79	22.40
Experiment: I9-C1							
$\sigma_{y,1}$	$\sigma_{y,2}$	$\sigma_{y,3}$	$\bar{\sigma}_y$	e%	d	S	S_e
1056.84	1115.04	1140.97	1104.28	1.68	18.22	43.08	24.87
Experiment: I9-C2							
$\sigma_{y,1}$	$\sigma_{y,2}$	$\sigma_{y,3}$	$\bar{\sigma}_y$	e%	d	S	S_e
1123.94	1020.9	1129.65	1091.5	0.5	5.44	61.21	35.34

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