THE ROLE OF STRUCTURAL DEFECTS IN HYDROGEN INDUCED COLD CRACKING OF STEEL WELDMENTS

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The new model of Hydrogen Induced Cold Cracking is presented. This model is based on the data of the mechanical tests and the results of experimental studies using modern analytical methods (SIMS, SEM, TDS). The latest achievements of physics of metals are taken into consideration. The fundamental of this model is the hydrogen interaction with the defects of a metal structure. The HICC mechanism is described begining with a solution of hydrogen in metal and ending with a formation of microcrack.

INTRODUCTION

Hydrogen Induced Cold Cracking (HICC) of weldments causes the most serious technological problems during welding of high strength steels and functioning of welded constructions in industry, energetics, aerospace technique. The key features of HICC have been experimentally found. A tendency to embrittlement is most pronounced at normal temperature and it depends on some factors: 1) steel microstructure, 2) content of hydrogen in a welded joint, 3) external and internal stresses arising in weldment after welding and 4) deformation rate.

The susceptibility to the embrittlement is considerably increased with defects that are stress raisers. However, structural defects such as vacancies, solute atoms, dislocations, grain boundaries, second phase particles, voids, nonmetallic inclusion are of considerable impotance in the process of HICC (1). This is due to the fact that they are able to accumulate of vastly more hydrogen content than regular lattice sites. And this hydrogen is held in the place to certain temperature.

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The objective of this investigation was a determination of HICC physics nature considering influence of structural defects on this process.

EXPERIMENTAL PROCEDURES

The test specimens used in this investigation were produced from high strength low carbon low alloy steel with chemical composition (wt. %) controled by opticospectral analysis:

0.14 C; 0.25 Si; 0.75 Mn; 1.00 Cr; 3.5 Ni; 0.14 Mo; 0.012 S; 0.025P.

Structure state in heat-affected zone (HAZ) arised after welding was simulated by high-heat treatment.

Hydrogen was introduced into specimens, by room temperature cathodic charging. Charging was carried out at a current density of 10 mA/cm^2 to concentration of diffusible hydrogen from 0 to 5 ml/100g of metal. The diffusible hydrogen contents were measured using the chromatographic method.

Two series of experiments were carried out. The first series was determination of temperature dependence of mechanical properties such as yield stress, stress at fracture, reduction of area at various strain rates. It was tensile test of hydrogen-free and hydrogen-charged specimens. The second series was acquisition of thermal desorption spectra of hydrogen from hydrogen-charged specimens.

Mechanical tests were carried out at temperatures from 77 to 293K with standard cylinder specimens. The test machine "Instron-1251" was used. The test data were processed by special computer program.

The thermal desorption spectra of hydrogen were obtained by high sensitive mass-spectral device MX-7304A ("Electron", Ukraine). Its resolution capability at 10% of intensity of mass-spectral line is no less than 1M, and hydrogen threshold of sensitivity is no more than $7{,}5 \cdot 10^{-11}$ Pa. Specimens were heated in a vacuum to temperature above 873K at a constant heating rate of 7K/min.

RESULTS

The hydrogen influence was estimated by variation of reduction of area of hydrogen-free and hydrogen-charged specimens (ψ and ψ_H respectively). Fig. 1 shows the diffusible hydrogen content dependence of hydrogen embrittlement degree ψ_H / ψ of steel. It is seen from Fig. 1 that the hydrogen have a pronounced effect on a plasticity of this steel. The noticeable change of plasticity takes place even at concentration of diffusible hydrogen ($[H]_{diff.}$) as few as 0.3 ml/100g. And catastrophical embrittlement of specimens occurs at $[H]_{diff.}$ =3 ml/100g (value of ψ_H / ψ approaches zero).

Fig. 2 shows temperature dependence of the reduction of area at two deformation rates (2 mm/min and 2000 mm/min) for hydrogen-free and hydrogen-charged specimens. It is seen that the higher the strain rate involved, the less pronounced the embrittlement becomes.

However, not all mechanical properties are changed by the action of hydrogen so strongly. The yield stress of hydrogen-free and hydrogen-charged specimens are very nearly equal. Fig.3 shows the experimental data of yield stress at various temperature for hydrogen-free and hydrogen-charged specimens. The content of diffusible hydrogen in the second case was 3 ml/100g. It is seen that all data took up one curve practically. Consequently, hydrogen doesn't influence on yield stress.

The thermal desorption spectra of hydrogen from hydrogen-free and hydrogen-charged specimens are illustrated in Fig.4. The curve of the desorption of hydrogen from hydrogen-free specimen (curve 1) is near-horizontal line. It is the background of residual gas of the mass-spectrometer. The curve of the desorption of hydrogen from hydrogen-charged specimen (curve 2) has clearly defined peak at temperature 400K.

DISCUSSION

It is required correct concept of physical nature of the embrittlement due to hydrogen for comprehensive description of the HICC process. In contemporary literature this process is explained by action of some factors such as pressure of molecular hydrogen in microvoids of metal, a decrease of interatom bonds in metal under the influence of dissolved hydrogen, adsorption phenomena, chemosorption of hydrogen on inner sufaces, peculiarities of hydrogen solubility in iron, diffusible anomalies, interaction of dissolved hydrogen with dislocations, chemical interaction of hydrogen with components of steel (2).

Using this factors as the base a number of hypotheses of hydrogen embrittlement have been proposed. But the principal demerit of theirs is a consideration of only a some part of so complicated process as HICC . In addition in none of the current hypotheses the role of structural defects of metal in Hydrogen Induced Cold Cracking of steel weldments is disregarded in full measure. Because of this, the attempts of explaining of the mechanism of HICC formation on the basis of one of theirs are imperfecly successful.

New model of HICC

From the above reasoning it is clear that a fundamental understanding of processes taking place during the cracking hasn't been attained yet. In this connection the new model of HICC is presented. It is based on the results of experimental studies using modern analytical methods (SIMS, SEM, TDS). The latest achievements of physics of metals and fracture mechanics are taken into consideration. In accodance with this model, in a metal volume during plastic deformation the submicrocrack is formed with one of dislocation mechanismes, or in consequence the microcleavage of a secondary phase particle, carbon formation, nonmetallic inclusion. The hydrogen, wich was transported by dislocations or concentrated near by dislocation barrieres before deformation, is absorbed on the juvenile sufaces of the microcrack in a state of negative ions H^- (3). As a result this microcrack loses the elastic equilibrium at the moment of its initiation, overcomes the potential barrier and propagates in a stress field autocatalitically. Thus the defects of a metal structure (dislocations, interphase and intergrain boundaries, secondary phase particles, carbon formations, nonmetallic inclusions) and hydrogen interaction with them play a decisive role in the HICC mechanism.

As indicated in Fig.1, embrittlement action of hydrogen can not be result of change of any properties of metal macrovolume. It has localize character, because hydrogen influence is found even at $[H]_{diff.}$=0.3 ml/100g. That little hydrogen concentration is few for the influence on interatom bonds in all metal volume.

The deformation rate dependence of hydrogen influence degree (Fig. 2) confirms the fact that the transport of hydrogen to site of its locale action plays a decisive role in the embrittlement due to hydrogen. From Fig.2 follows that the efficiency of hydrogen transport specifies by conditions of deformation process. Because in plastic deformation the process of hydrogen transport is realized by dislocation mechanism. It unambiguously confirms the validity of the concept of dislocation transport of hydrogen.

It follows from Fig.3 that the presence of hydrogen in the metal doesn't influence on the yield stress, that is, the hydrogen condensed at dislocations doesn't influence on its motion. It is caused by two factors such as an anomaly high diffusible mobility of hydrogen and a moderately low bond energy of hydrogen with dislocation. It is confirmed by data shown on Fig.4. The peak of termal desorbtion curve is the hydrogen released from the dislocations. To do this suffices to heat the metal to temperature about 400K.

Hence the HICC mechanism may be described, on new model grounds, beginning with a solution of hydrogen in metal and ending with a formation of macrocrack. It wasn't able to achieve before. Sound suppositions of the known hypotheses of the hydrogen embrittlement are combined in the new model. At the same time this model allows to overcome the troubles and the weak points of the hypotheses and in full measure unveils the role of structural defects in Hydrogen Induced Cold Cracking of steel weldments.

SYMBOLS USED

Ψ = reduction of area of hydrogen-free specimens (%)

Ψ_H = reduction of area of hydrogen-charged specimens (%)

σ_T =yield stress (Pa)

$[H]_{diff.}$ = concentration of diffusible hydrogen (ml/100g)

V =deformation rate of hydrogen-free specimen (mm/min)

V_H =deformation rate of hydrogen-charged specimen (mm/min)

T =temperature (K)

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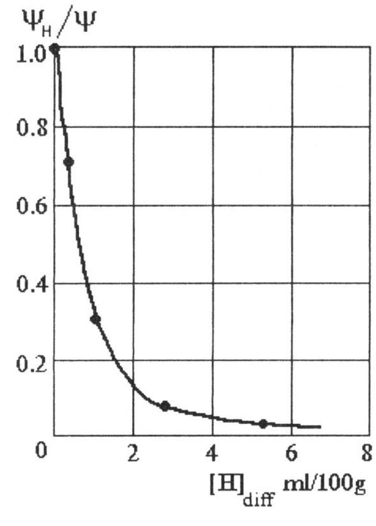

Figure1 The hydrogen embrittlement versus the hydrogen content

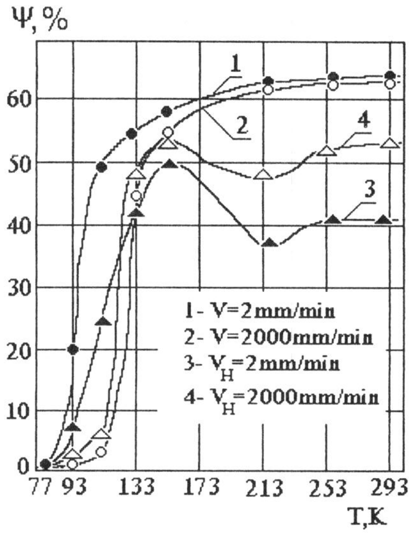

Figure2 The reduction of area versus the temperature

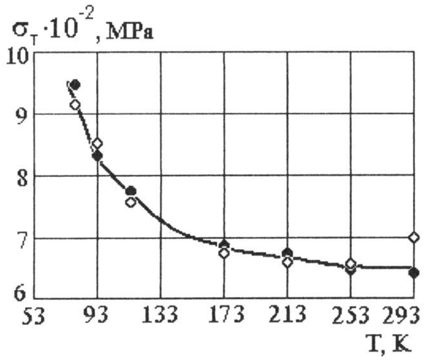

Figure3 The yield stress versus the temperature

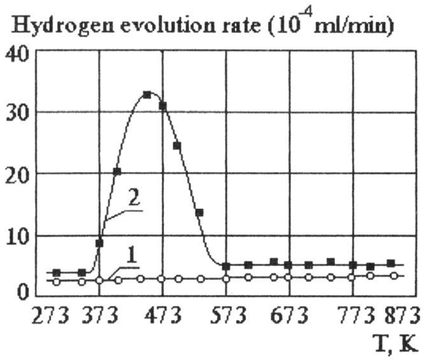

Figure4 The thermal desorption spectra of hydrogen