PECULIARITIES OF CORROSION-EROSION FRACTURE OF PIPELINE STEEL

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Micro-hardness (Hμ) measurements are performed which show that in microstructure components of a ferrite-pearlite steel subject to liquid cavitation hardening and softening processes proceed stage by stage. A resulting Hμ level displays which of these processes dominate in a prescribed microstructure component: as a result the pearlite is hardening and ferrite is softening. Is shown that the scatter of the microhardness reflects inhomogeneity and localisation of plastic deformation in a surface layer of the steel. It is shown that the deformation processes can be related with microstructure changes, namely degradation of pearlite grains. The rate of corrosion-erosion wear correlates not with HRB, reference values of Hμ, but with its resulting level.

INTRODUCTION

Corrosion-erosion wear (CEW) of structural materials is complex process, which proceeds on a interface of two phases at effect of cavitation. Its development is determined by properties of both phases, as well as by intensity of their interaction. In recent years many investigations were performed upon determination of relations between the CEW rate and one of the tensile properties or combination of these characteristics. This problem is well described in the papers of Preece (1), Hammit (2), Okada and Yoshiro (3). In the majority of works it is assumed that the energy exposed to a specimen subject to micro-impact cavitation effect of environment is absorbed by the material body. A bigger part of energy is absorbed in a kind of inelastic deformations. Therefore the material ability to absorb energy of cavitation micro-impacts is the governing factor. Various combinations of tensile properties were suggested as the parameters to describe material ability to absorb cavitation energy, namely: Í; σ_y; E_e; E_c; E_F; E_cxH; E_exH; σ_F^2 + %S.

The investigations of mass transfer did not provide us with simple relationships between the CEW rate and the tensile properties which can be used in

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wide purposes. However in some cases depending on material type a good correlation with the parameters such as H, E_cxH, E_exH was obtained. Thus H can be treated as a universal characteristic for finding correlation dependencies and can replace other force characteristics, including σ_F and σ_{UTS}. Use of microhardness in evaluation of the properties of microstructure components and their change during the cavitation (Romaniv et al (4)) is of special interest.

EXPERIMENTAL PROCEDURE

The specimens made of the ferrite-pearlite Cr-Mo-V steel in virgin state and the specimens cut from pipelines after 156,000 hours of operation were investigated. Their tensile properties are shown in Table.

TABLE Tensile Properties of the Steel before and after the Operation

	σ_Y, MPa	σ_{UTS}, MPa	HRB*	τ_i^{**}, h	m^{**}, mg/h mm^2
Virgin material	280	470	76/75.5	0.5/4.0	0.408/0.011
After the operation	240	435	71/69	0.75/5.3	0.257/0.007

* The numerator (denominator) contain HRB values before (after) the cavitation.
** Data in the numerator concern the tests in water and in the denominator - in oil.

CEW tests were performed with use of magnetostrictive drill (frequency 20kHz, amplitude 36 μm). CEW rate was measured by the weight method. The working environments were water (pH 6.5) and kerosene.

RESULTS

Irrespective of the working environment three areas can be seen in CEW rate - τ curves representing: an incubation period τ_i, sharp rise and steady-state growth. Metallographic examinations have shown that the polished surface of the specimen changes a little during the incubation period. It has allowed to measure the change of hardness HRB and microhardness of microstructure components on surfaces of tested steels during the cavitation. After the cavitation HRB has not practically changed (Table). On time dependences of averaged Hμ values both for ferrite and pearlite three area are also observed: rise of Hμ, decrease and a constant level (Fig. 1). When the tests were performed in water the deformation processes proceed more intensively. In the tests in oil three areas are more distinct, while absolute maximum and steady-state Hμ values are a little higher. In Fig. 1 the averaged Hμ values are presented. Large Hμ scatter can be observed (Fig. 2). The scatter is wider in areas of increase and drop of Hμ. This scatter is not caused by imperfections in the test technique, as far as for the initial surface (τ=0) no significant scatter is observed. It is also not induced by curvature of initially plane surface during the cavitation, as at transition from the second to the third area the scatter decreases. The deformation in surface layers of the virgin material is accompanied by microstructure changes. Metallogrphy examinatons showed that during the incubation period a mosaic structure of the ferrite-cementite mix of pearlite grains disappears. This made their identification as the pearlite grains difficult. Micro-hardness of pearlite grains does not practically differ from Hμ of ferrite grains. By the secant method it was found that by the end of the incubation period the number of pearlite grains in the virgin material decreases in 2-3 times.

For the virgin material the incubation period is shorter and CEW rate is higher than that in having been in service (Table). In the tests made in oil CEW rate was lower more than 10 times. The increase CEW rate after the incubation period is caused by occurrence of the centres of microfracture, which are similar to pits in pitting corrosion. Is has been found that corrosion-erosion pits are often formed in degraded pearlite grains. With an increase of test time the number of pits on the surface grows, their growth and coalescence in certain favourable directions occurs. This moment is the beginning of the steady-state CEW. After that on the surface well-known ray are formed, where the cavitation fracture is localised.

DISCUSSION

The received results yield that in surface layers the cavitation causes not only the strain hardening (Fomin (5)), which is observed in the initial period (Fig. 1).Then in the mechanical behaviour of the steel after strain softening and stabilisation of properties can be seen. The processes of hardening and softening in pearlite grains proceed more intensively and resulting Hμ level is far below the reference value. For the ferrite grains these processes are more delayed in time. Unlike the pearlite behaviour the resulting ferrite Hμ level in higher than the initial. Thus under the cavitation effect, the pearlite phase is softening, and the ferrite is hardening. The resulting Hμ level displays which of processes - hardening or softening - dominates in each material microstructure component. At the same time, HRB is not sensitive to these changes (Table). It does not also reflect the material resistance to CEW.

Difficulties in finding general laws basing on these mechanical parameters occur because the material CEW resistance is determined not by convenient tensile properties but by the strength of separate microvolumes. In structural materials there is a significant inhomogeneity of a structure and properties of microvolumes. Favourably oriented grains (subgrains) are disposed to shear and fracture. Others render high resistance to plastic deformation. Furthermore localisation of plastic shear and fracture are affected also by inhomogeneity of cavitation microimpacts.

About inhomogeneity of surface deformation under the effect of cavitation one can judge by Hμ scatter (Fig. 2). It has a maximum value at the hardening-softening stage, and decreases at exhaustion of plasticity, as well as at transition from ferrite to pearlite. A similar deformation behaviour is observed in fatigue loading of steels (Romaniv et al (4)). It should noted, that the duration of the incubation period does not coincide with the end of the hardening-softening stage. It can be interpreted in such a manner that the processes of corrosion-erosion fracture, as well as fatigue, are initiated in the material after exhaustion of its plasticity. These results confirm the approaches, which consider the nature of fracture process under cavitation and fatigue from general positions. They allow to receive a good correlation of the incubation period and the CEW rate with such combined parameters as σ_F' x n' (Richman and Mc Naugtion (6)) and ε_F' x H (Kang et al (7)). It is noteworthy that both parameters include both force σ_F', H and deformation ε_F', n' criteria. However, for wide application so different criteria appear to require further development. In particular, the results of this work show that CEW rates of the steel in initial state and after the operation are determined not by reference HRB and Hμ values but by the steady-state Hμ level of weakest microstructure component. It is often assumed (Preece (1), Fomin (5)), that in ferrite-pearlite steels the cavitation failure is localised in ferrite grains. However, the results of the present work show that differences of strengths and failure probabilities of ferrite and degraded pearlite grains are insignificant.

There are also convincing data on CEW influence on the packing defect energy (Preece (1)) as well as on the Young modulus E (Krupicz et al (8)). However, when accounting for E it should be considered that it has different effect on cavitation and fatigue fracture: with reduction of E the material resistance to cavitation failure increases and the resistance to fatigue fracture decreases.

From the above mentioned it is possible to conclude about universality of the Hμ characteristic for finding the correlations. However, Hμ reflects only changes of the material mechanical properties at environment cavitation. When comparing the test results in water and oil no considerable distinctions in deformational behaviour of microstructure components have been observed, while the CEW rates differ more than 10 times. Obviously, the CEW rate is affected also by such properties of the metal and liquid environment, which determine the nature and intensity of adsorption, electrochemical and absorption processes on the interface.

SYMBOLS USED

H, H_μ, HRB, ΔH_μ = hardness, microhardness, Rockwell hardness, and averaged microhardness scatter

σ_p, σ_y, σ_{UTS} = proportionality stress, yield stress, ultimate tensile strength (MPa)

σ_F, σ_F' = actual fracture stress at active static and cyclic loading respectively (MPa)

n, n' = strain hardening exponent at active static and cyclic loading respectively

ε_F, ε_F' = fracture strain at active static and cyclic loading respectively

$E_e=\sigma_{ys}^2/2E$ = energy of elastic deformation (kJ)

$E_c=\sigma_F^2/2E$ = critical energy of deformation (kJ)

E_F = energy of fracture deformation (kJ)

τ_i = incubation period of corrosion-erosion wear (min)

%S = relative cross-section reduction at cavitation

REFERENCES

(1) Erosion. Treatise on Materials Science and Technology, Edited by C.M. Preece, Vol. 16, Academic Press, New York, U.S.A., 1979.

(2) Hammit, F.G., "Cavitation and Multiphase Flow Phenomena", McGraw-Hill, New York, U.S.A., 1980.

(3) Okada, T., Yoshiro, I., Bull. SME Int. J., Vol. 33. No. 2, 1990, pp. 128-135.

(4) Romaniv, O.M., Yarema, S.Ya., Nykyforchyn, H.M., et al., "Fatigue and Fatigue Crack Growth Resistance of Structural Materials", Naukova Dumka, Kyiv, Ukraine, 1990 (in Russian).

(5) Fomin, V.V., "Hydroerosion of Metals", Mashinostroenie, Moscow, 1977.

(6) Richman, R.H. and Mc Naugtion, W.P., Wear, No. 140, 1990, pp. 63-82.

(7) Kang, Z., Chenging, G., Fusan, S., and Bingzhe, L., Wear, Nos. 162-164, 1993, pp. 811-819.

(8) Krupicz, B., Kondrat, Z., Heift, R., and Lukaszewicz, K. "Mechanical Properties of Materials and Their Resistance on Cavitation Errosion", Extended Abstracts of the 5th Int. Symp. on Creep and Coupled Processes, Byalystok, Poland, Edited by A.Jakowluk, TU Bialystok Press, Poland, 1995.

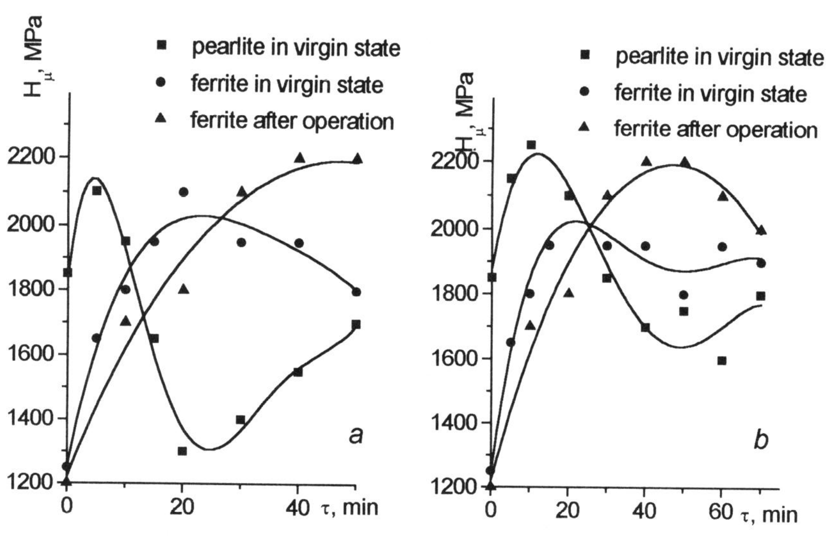

Figure 1 Dependence of the microhardness H_μ on cavitation time water (a) and in oil (b).

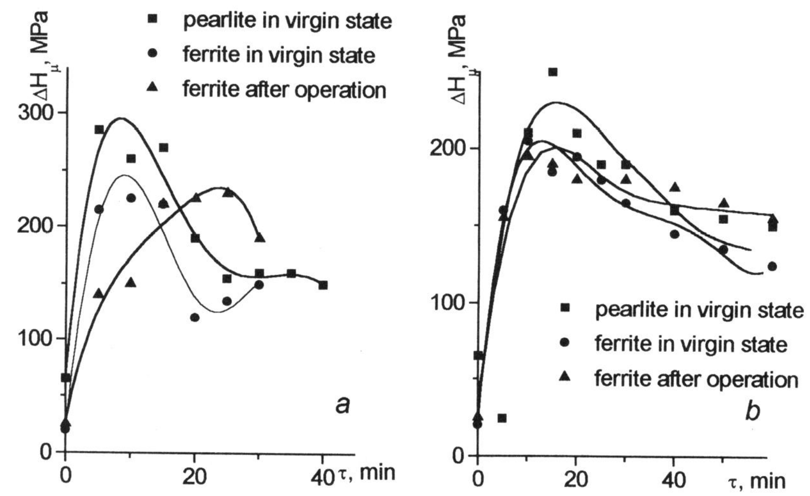

Figure 2 Dependence of the average microhardness scatter ΔH_μ on cavitation time in water (a) and in oil (b).