HYDROGEN EFFECT ON HIGH-TEMPERATURE DEGRADATION OF A Cr-Mo-V STEEL

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Investigations of degradation processes of a Cr-Mo-V steel are presented with further applications of the fatigue fracture mechanics approaches for evaluation of material damage degree. For acceleration of the steel degradation process specimens were exposed to thermocycling in a gaseous hydrogen environment. The characteristics of fatigue crack growth in the material damaged in laboratory are compared with the its characteristics after long-term operation in a steam power plant.

INTRODUCTION

Hydrogen formation during the contact of a stressed metal with corrosive environment and its penetration into a deep metal causes a number undesirable effects. At high temperatures, typical for power plant operation, first of all there is a problem of degradation of the microstructure and properties of the virgin material (Nykyforchyn et al (1)). In this connection, investigations of laws of materials degradation and methods for their evaluation are of great importance. The solution of the problem is complicated by long duration of laboratory tests. The present work is an attempt of laboratory simulation of the material degradation process in an accelerated mode with further application of the approaches fatigue fracture mechanics for evaluation of the material damage degree.

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MATERIAL TESTED AND EXPERIMENTAL PROCEDURES.

A steam pipe-line Cr-Mo-V steel was tested in initial conditions and after the operation in a steam power plant (temperature of 540 °C, steam pressure of 5MPa) during 48,000, 140,000, and 190,000 hours, as well as after laboratory treatment simulating material degradation in power plant service. The chemical composition and the tensile properties of the steel are shown in Table 1 and Table 2 respectively.

TABLE 1 - Chemical Composition of the Investigated Cr-Mo-V Steel

C	Cr	Mo	V	S	P	Si	Mn
0.1	1.10	0.26	0.17	0.019	0.015	0.26	0.54

TABLE 2 - Tensile Properties of the Cr-Mo-V steel at Room Temperature

τ_{op}, h	σ_{UTS}, MPa	σ_y, MPa	δ , %	ψ ,%	Hμ, MPa
0	470	280	29	75	1790
48,000	440	240	33	66	1740
140,000	450	250	27	77	1720
190,000	460	260	25	77	1710

For simulation of the operation-induced degradation laboratory specimens were exposed to high-rate thermocycling in a gaseous hydrogen environment of a pressure of 0,3 MPa in a temperature range of 100..570 °C; number of thermocycles was varied from 13 to 100. In this purpose the specimen without loading were being heated to the working temperature 570 °C, held one hour at this temperature and then abruptly cooled during 1-2 minutes to the low temperature. The low temperature does not give possibility for hydrogen to leave the metal, hence the high local stresses must appear in the metal. After this treatment the specimen were heated to 570 °C for desorption of hydrogen from the metal. The degree of material degradation was evaluated by measuring the rates of fatigue crack growth at the room temperature in 180x22x15 and 180x22x7 mm beam specimens subject to cantilever bending. The crack closure effect was evaluated by using a technique of Nykyforchyn et al (2).

TEST RESULTS AND DISCUSSION

In Fig. 1 results of the tests are compared for the Cr-Mo-V steel in the virgin state and after the operations of different periods τ_{op}. The relations da/dN - ΔK and da/dN - ΔK_{eff}, show existence of ambiguous effect of operation time on the crack growth rate. Fig. 2 is shows how the parameters ΔK_{th}, $\Delta K_{th\ eff}$, $\Delta K_{th\ cl}$, and U_{th} change in the threshold area of loading, e.g., at a operation periods up to 140,000 hours ΔK_{th} increases from 6.2 to 6.8 MPa $m^{1/2}$ and at 190,000 hours it decreases to 5.2MPà $m^{1/2}$. However the effective threshold $\Delta K_{th\ eff}$ monotonically decreases with an increase of the operation period. With an increase of τ_{op} closed part of ΔK_{th}, named $\Delta K_{th\ cl}$, changes similarly to ΔK_{th}, i.e. passes through an extremum, corresponding to 140000 hours of operation. The crack closure factor U_{th} monotonically decreases by increasing τ_{op} up to 140,000 hours. The further increase of operation time does not affect significantly on U_{th} (Fig. 2).

In Fig. 3 are test results on fatigue crack growth rate in steel in virgin state and after the thermocycling in gaseous hydrogen are plotted. Similarly to Fig. 2 (for the material damaged in operation), an ambiguous effect of number of thermocycles on ΔK_{th} is manifested, which is not found when the crack closure effect is taken into account. Comparison of the results presented in Figs. 2 and 4 indicates the same qualitative change of threshold parameters crack growth in the material after the operation and laboratory degradation. However it should noted, that in tests on effects of laboratory treatment on fatigue fracture thinner specimens (7 mm) were used, which were more sensitive to the crack closure.

The analysis of experimental results confirms conclusions made by (Nykyforchyn et al (1)) about the prospects for using the fatigue fracture mechanics approaches in evaluation of the degree of high-temperature degradation of structural alloys. Obviously, it is that parameter to be the most sensitive to material degradation which provides the most local fracture. In this connection the threshold characteristics of fatigue crack growth are the most preferable. Thus only $\Delta K_{th\ eff}$ can unambiguously characterise the degree of material degradation since ΔK_{th} is the integral characteristic of the fatigue crack growth resistance and the crack closure. Naturally, at high load ratio, which is closer to actual operating conditions of power plant steam pipelines, positive effect of the crack closure should not be expected.

In our opinion, the proposed material treatment by thermocycling in hydrogen media appears to have prospects in simulation of long-term operating damage of power plant steels. Good agreement between experimental results on fatigue crack growth rate in materials damaged in service and in laboratory specifies a possibility of seeking correlation between operation duration and number of thermocycles in hydrogen media. Such a correlation would be helpful for development of methods for residual lifetime assessment of structures which will take into account high-temperature materials degradation.

SYMBOLS USED

σ_y = 0.2% yield stress (MPa)

σ_{UTS} = ultimated tensile strength (MPa)

δ = elongation (%)

ψ = reduction of cross-section area (%)

da/dN = fatigue crack growth rate (m/cycle)

$U_{th} = \Delta K_{th\ eff} / \Delta K_{th}$ = threshord crack closure ratio

$\Delta K, \Delta K_{eff}$ =nominal and effective ranges of stress intensity factor SIF (MPa $m^{1/2}$)

$\Delta K_{th}, \Delta K_{th\ eff}$ = nominal and effective threshold SIF ranges (MPa $m^{1/2}$)

$\Delta K_{th\ cl} = \Delta K_{th} - \Delta K_{th\ eff}$ = ineffective threshold SIF range (MPa $m^{1/2}$)

τ_{op} = operation time (h)

n = number of thermocycles

Hμ = microhardness (MPa)

REFERENCES

(1) Nykyforchyn, H.M., Student, O.Z., Milanoviè, D., and Loniuk, B.P. "Damage Kinetics in Materials for Power Equipment and Its Effect on Fatigue Fracture Characteristics", Proceedings of an International Symposium on Materials Ageing and Component Life Extension, Milan, Italy, "Materials Ageing and Component Life Extension", Vol. II, Edited by V. Bicego, A. Nitta, R. Viswanathan, EMAS, Warley, U.K., 1995.

(2) Nykyforchyn, H.M., Andrusiv, B.M., Voldemarov, A.V., and Kutsyn, M.A., Physicochemical Mechanics of Materials, Vol. 18, No. 5, 1982, pp. 100-103 (in Russian).

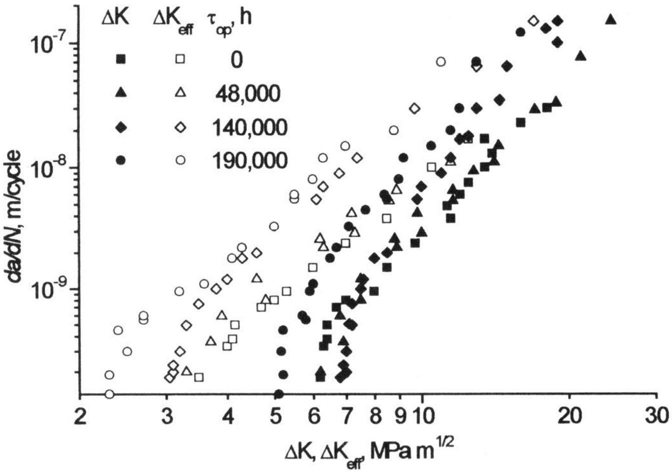

Figure 1 Effect of operation on the fatigue crack growth rate in 22 mm thick specimens at load cycle frequency 10 Hz and zero load ratio.

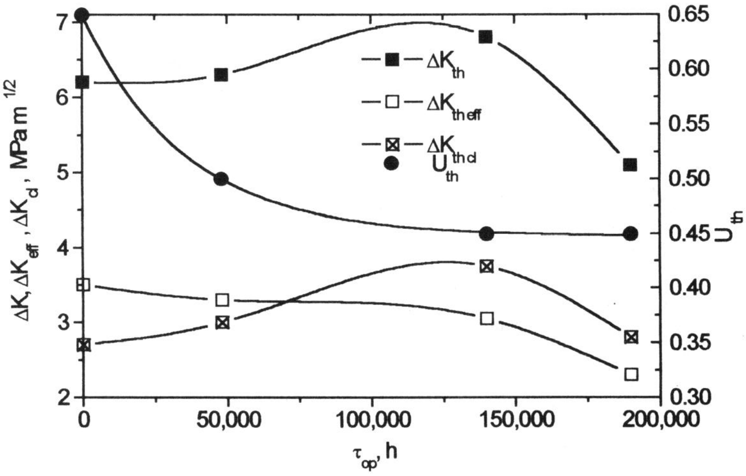

Figure 2 Effect of long-term operation on the threshold characteristics of fatigue crack growth.

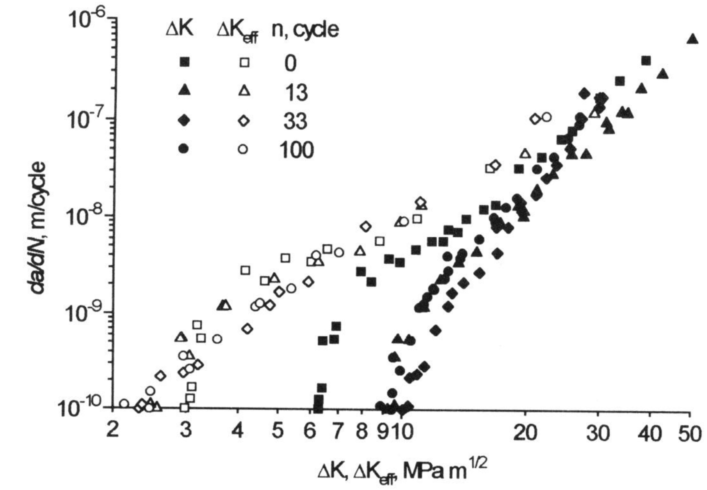

Figure 3 Effect of thermocycling in hydrogen on the fatigue crack growth rate in 7 mm thick specimens at load cycle frequency 10 Hz and zero load ratio.

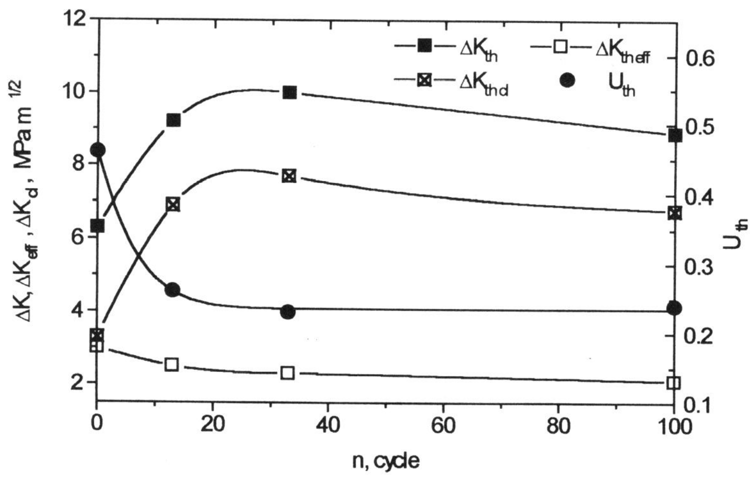

Figure 4 Effect of thermocycling in hydrogen on the threshold characteristics of the fatigue crack growth.