FATIGUE CRACK GROWTH RESISTANCE OF HK-40 STEEL IN GASEOUS HYDROGEN

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INTRODUCTION

The influence of hydrogen on the fatigue crack growth in the wide range of temperatures is among the main problems in fatigue fracture mechanics. There is a large body of literature in this area for low temperatures, including room temperature (Romaniv et al., 1988, Nykyforchyn et al., 1990a), but high temperature fatigue in hydrogen needs more detailed research. This paper continues the previous studies (Nykyforchyn et al., 1990b, Romaniv et al. 1990) and elucidates the laws of hydrogen effects on the fatigue crack growth resistance of heat-resistant HK-40 steel in the temperature range 20...800°C.

EXPERIMENTAL PROCEDURES

The material tested was HK-40 steel (in wt %: C - 0.36, Mn - 0.51, Si - 1.32, Cr - 24.6, Ni - 20.64, P - 0.021 and Fe - balance) with its basic mechanical characteristics under tension as follows: UTS = 480 MPa; σ_{ys} = 290 MPa; R.A. = 24%; elongation 4,3%.

The tests on fatigue crack growth resistance were carried out on circular ring specimens which were cut from the reforming furnace pipes 115 mm in diameter and 20 mm working section. Type of specimen loading is uniaxial tension (Fig.1). The heating of the specimen was performed by electric current flow through the specimen working section. CIF was determined according to methodies (Methodological recommendations, 1986). In account for the conjectural character of CIF usage at high temperatures, the investigations were done in the narrow range of crack length (10...14mm). The crack closure (CC) was determined by a strain gauge which recorded the displacement along the line of load application.

The tests were carried at 20°, 200°, 400°, 600° and 800°C in pure hydrogen (P_{H_2} = = 0,3MPa), vacuum (P = 0.13Pa) and laboratory air. The loading cycle parameters were: R = 0.1; f = 1 Hz (in the air f = 10 Hz at 20°C).

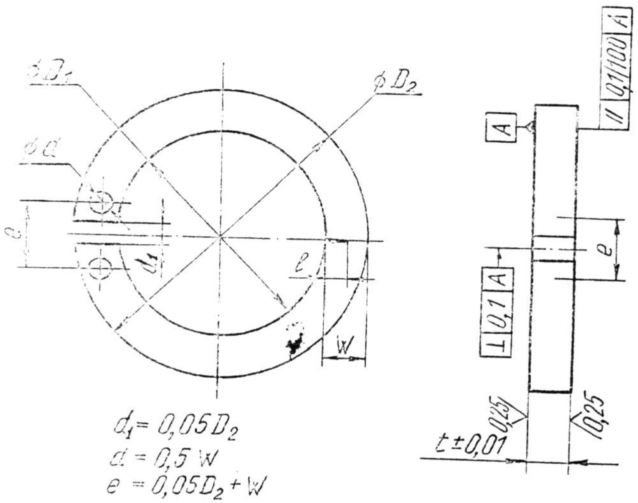

Fig. 1. A sketch of ring-type specimen for the crack resistance testings at high temperature.

EXPERIMENTAL RESULTS

Fatigue fracture kinetic diagrams are plotted for nominal and effective cyclic stress intensities at Fig. 2,3. Fatigue crack growth (FCG) accelerates with the increase of temperature irrespective of environment type. In comparison with vacuum laboratory air retards the high temperature FCG. If one takes CC effect into account it can be argued that crack edges oxidation during testing in the air stipulates the existence of such an effect.

The effects of hydrogen on the FCG are very ambiguious, depending on the test temperature and the loading level. At high SIF hydrogen accelerates FCG practically in the whole temperature range, but by increasing the temperature this effect reduces, and at 800°C it is noticeable. At low SIF and temperatures up to almost hydrogen retards FCG. A temperature rise to above 400°C changes the positive influence of hydrogen into the negative one. Accounting for CC does not change the relative positions of nominal and effective fatigue fracture kinetic diagrams qualitatively. An exception occurs only at maximum temperatures when FCG rate relative to ΔK_{eff} does not depend on type of environment, though this dependence reveals.

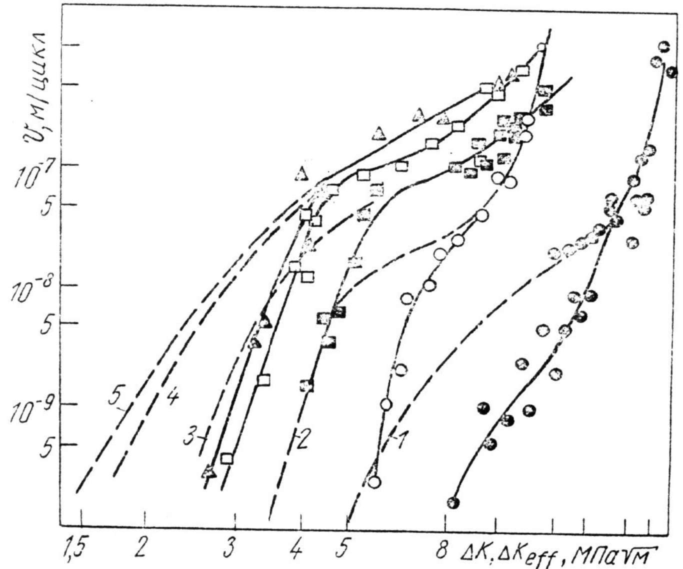

Fig.2. v - ΔK (symbols) and v -ΔK $_{eff}$ (lines) dependences for HK-40 steel in hydrogen at different temperatures : 20°C (●,1) ; 200°C (○,2); 400°C (■,3); 600°C (□,4); 800°C (▲,5).

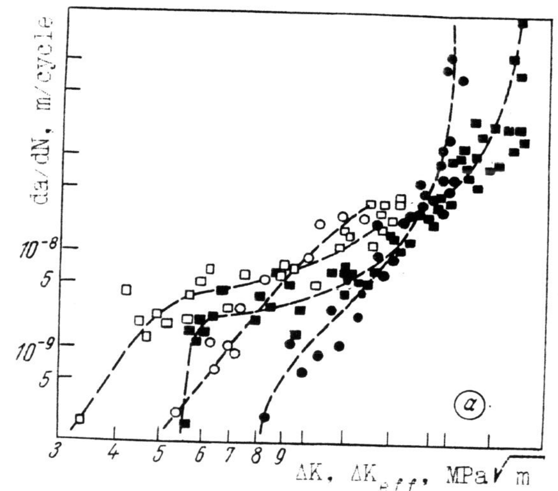

Fig.3. Fatigue fracture kinetic diagrams of HK-40 steel in the air (■,□) vacuum (▲,Δ) and hydrogen (●,○) at temperatures: a - 20°C; b - 200° ; c - 400° ; d - 600° ; e - 800°C. Dark dots correspond to nominal SIF values, light - to effective.

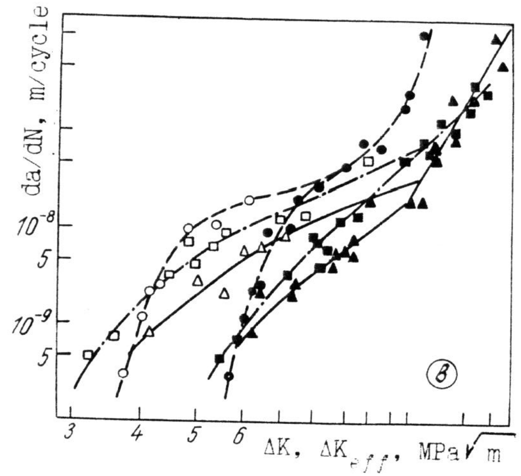

Fig.3,b.

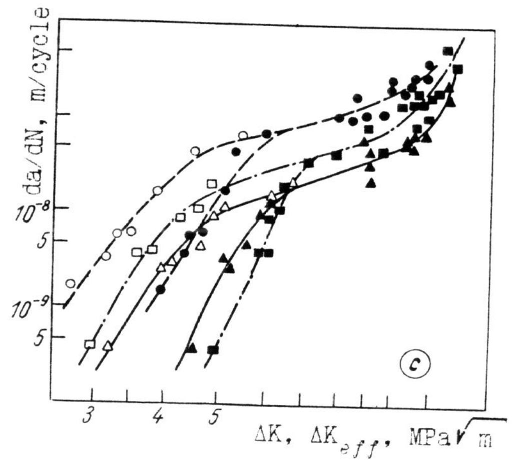

Fig.3,c.

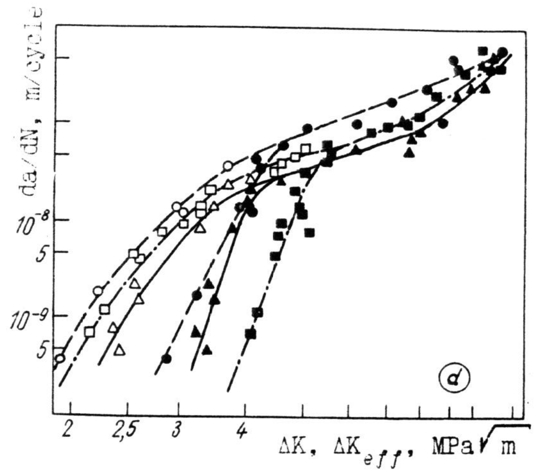

Fig.3,d.

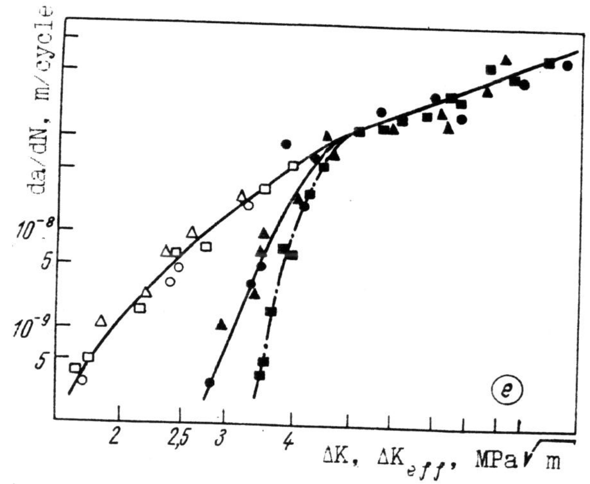

Fig.3,e.

DISCUSSION

An inversion of influence of gaseous hydrogen on loading level at low temperatures is confirmed many times in literature (Romaniv et al., 1988, Fracture Mechanics .., 1990). Negative effects of hydrogen at high SIF are connected with the decrease of rapture resistance that is characterized fractographically by a great amount of cleavage on the fracture surface. However, for FCG at low SIF (close to the threshold) the rise of $\Delta K_{th\ eff}$ level in hydrogen can be explained by the increase of shear resistance under the hydrogen influence.

The hydrogen inversion influence on FCG is peculiar not only for the effective fatigue fracture diagrams, but also for the nominal ones. It is explained by the fact that low temperature testing of HK-40 corrosion resistance steel does not assist the intensive oxide formation. Thus, the strengthening action of hydrogen (that is testified by higher $\Delta K_{th\ eff}$ values in hydrogen in comparison with that in the air) is dominant with respect to the change of CC that stipulates higher nominal ΔK_{th} threshold under the conditions of low temperature FCG in hydrogen.

The hydrogen influence on high temperature FCG (above 400°C) has its own peculiarities. In comparison with low temperature testings, an insignificant negative hydrogen effect at high SIF values is caused by the absence of both CC and cleavage areas on the fracture surface. At low SIF hydrogen accelerates FCG that can be explained by the absence of conditions for CC development according to oxide formation mechanism which is more intensive in the air at such temperatures. (Oxide formation stipulates the nominal high temperature fatigue threshold increase in the air in comparison with that in vacuum). But the hydrogen influence keeps negative also for the analysis of effective kinetic diagrams of fracture. Thus the strengthening effect of hydrogen,which is peculiar to low temperature fatigue changes for nonstrengthening by rising the temperature. In other words, hydrogen facilitates the plastic flow that results in the increase of the FCG rate in prethreshold region. Such a hydrogen influence has not only a lower limit, but also an upper temperature limit. At 800°C the effective diagrams in hydrogen and in the air practically superimpose. At this temperature hydrogen is not able to facilitate the plastic deformation, though its negative effect occurs in nominal coordinates and is stipulated by low CC, because hydrogen prevents the oxide formation.

Thus, hydrogen at high SIF causes a loss of material strength near the crack tip (practically up to 600°C) while at low SIF it may eighther strengthen the material (at 20°and 200°C), or cause the loss of crack growth resistance (at $T > 400$°C). That is there exists a certain T* temperature at which the change of hydrogen effect character occurs: $200°C < T^* < 400°C$. It should be noticed that especially in this range hydrogen leaves the defects, including dislocation (Archakov, 1979), where it stayed at lower temperature because of energetical advantage. It is shown (Romaniv, 1993), that at room temperature hydrogen increases the material resistance to plastic deformation. Thus it can be concluded that the strengthening action of hydrogen is stipulated by the dislocation density increase (hydrogen facilitates the dislocation generation, forming for himself energetically convenient places for precipitation). The oposite effect was observed during the creep tests in various environments (Vitovec, 1982). The change of inert environment for hydrogen at 427°C was accompanied by immediate acceleration of creep process (at lower temperatures such effect was not observed). Such an hydrogen influence, is connected with growth of mobility of dislocations, because the immediate rise of their density is impossible.

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