THE INFLUENCE OF HYDROGEN ON FRACTURE TOUGHNESS AND CRACK GROWTH IN TITANIUM ALLOYS

A.V. MALKOV, V.K. ALEXEEV and M.G. MISHANOVA
Moscow Institute of Aircraft Technology
Named after Zsiolkowski Moscow, Petrovka, 27

ABSTRACT

The influence of hydrogen on the survivability and cyclical fracture tougness of titanium alloy AT3 is studied referred to pseudo-α-class. Under conditions of pure fatigue hydrogen diminishes the survivability of specimen with cracks in the order of two. It is stated that cyclical fracture toughness k_{fc} doesn't coincide in absolute value with parameters k_c and k_{1c} determined by short-lived action of statistical load. The values k_{th} for different hydrogen concentrations are found from diagrams of durability built in coordinates k_{max} - the number of cycles before fracture. Hydrogen has a negative influence on the value k_{th} in a very close interval of concentrations. It is supposed that this kind of hydrogen brittlement has sinergetick nature.

KEY WORDS

Fracture toughness, Fatigue, Survivability, Hydrogen, Crack, Threshold of crack resistance, Critical hydrogen concentrations.

The efficiency of modern titanium structures is determined mainly by ability of material to withstand the development of hydrogen cracks (Malkov A.V. and Kolachev B.A.,1976; Kolachev B.A. and Malkov A.V., 1983; Kolachev B.A. and others 1982). The effectiveness of using the approaches of fracture mechanics is shown in a number of works in engineering practice by estimation of hydrogen fracture in titanium alloys under conditions of short-lived and prolonged statistical loads (Malkov A.V. and Kolachev B.A.,1979; Kolachev B.A. and others 1974). Information about the influence of hydrogen on crack resistance of titanium alloys by cyclical loading is contradictory (Kolachev B.A. and others 1974). In published works about hydrogen fatigue as arule smooth specimen or specimen with concentrator were used what doesn't allow to speak directly about the influence of hydrogen on fatigue crack growth because of effects of plastic deformation and nucleation of defects.

The present-day research is devoted to study of the influence of hydrogen on survivability and cyclical fracture toughness of pseudo-α-titanium alloys as materials most susceptible to hydrogen brittlement. Beam specimen with side crack were tested on the machine YRC 2000 according to the sheme tension-compression under conditions of pulsating load with freguency of loading of 33 Hc. Before preparation specimen (B) 3 mm thick sheet billets were hydrogen alloyed till predetermined concentrations with precision of ±10%. The fatigue crack was deposited on mechanical vibrator and **k** egual to 20-25% from value of criticall stress intensity factor determined by short-lived tests (k_c). Geometrical characteristics of specimen correspond to recomendations (Kudrjashov V.G.,1985). After conducting mechanical tests one took into account values got with specimen which meet the following conditions $a_o/w=0,15-0,2$ and $0,2<a_f/w<0,6$ where a_o and a_f is an initial and finishing length of fatigue crack measured directly on fracture and **w** - specimen width.

Analysis of values of fracture toughness (k_c and k_{fc}) and also values k_{max} (of initial stress intensity factor) were carried out according to formula: $k_{max}=(P_{max}Y)/(Bw^{1/2})$, where $Y=1,99(a_o/w)^{1/2}-0,41(a_o/w)^{3/2}+18,7(a_o/w)^{5/2}-38,4(a_o/w)^{7/2}+53,85(a_o/w)^{9/2}$ and P_{max} - maximum load in the cycle of loading. In the course of tests the value k_{max} didn't surpass $0,3k_c$ with taking into consideration that the fracture should occur under conditions of pure fatigue. The values of cyclical fracture toughness (Ivanova V.S. and Kudrjashov V.G.,1970) were considered being correct in such cases when the fracture was fully (100%) "straight" and plastic deformation on side surfaces was absent. Due to the results of tests there was built a diagram of durability in coordinates k_{max} - amount of cycles before fracture (fig.1).

From the data shown on fig.1 it follows that with the increase of hydrogenn content the type of fatigue curves varies. The asymptotic character of lower part of the durability curve is typical for the specimen with small hydrogen concentrations (0,003-0,015%) while by concentrations of 0,02-0,05% curves with clearly expressed horizontal sections are formed. The availability of physical or conditional values k_{max} can be interpreted as threshold spreading of initial crack (k_{th}) on base of $2\cdot10^6$ cycles. The values k_{th} are too sensitive to hydrogen (fig.2).

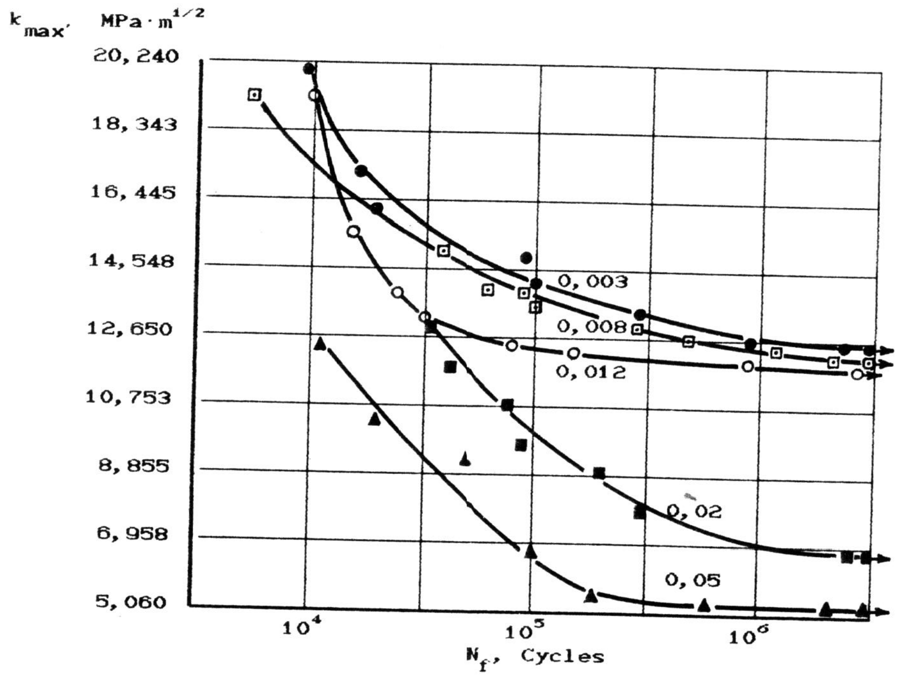

Fig.1. The influence of hydrogen and values of initial stress intensity factor (k_{max}) on the survivability of AT3.

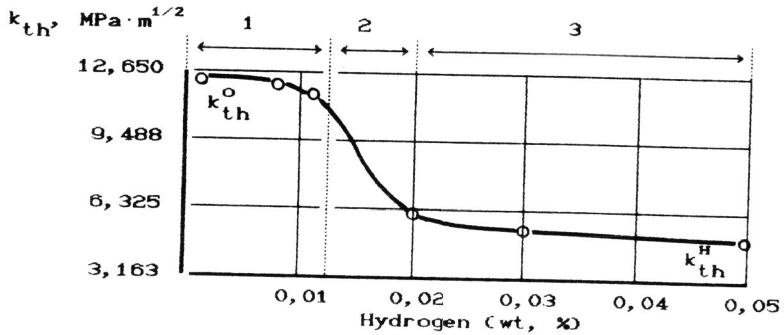

Fig.2. The influence of hydrogen on threshold values k_{th} of the alloy AT3 by cyclical loading on base $2\cdot10^6$ cycles.

The dependence of k_{th} - C_H for the alloy AT3 is characterized through the availability of two plateau-upper ($k_{th} \simeq 12{,}175$ MPa·$m^{1/2}$) and lower ($k_{th} \simeq 5{,}1$ MPa·$m^{1/2}$) and as to mechanism of fracture stated according to the results of microphractographical analysis (Malkov A.V. and others, 1982) of three fields: 1 - field of mechanical damage (typical relief ingrained ribbed facets; negative influence of hydrogen is negligible, though perhaps hydrogen intensifies the process of mechanical failure to some extent; level of upper plateau (k^o_{th}) is defined through the nature and microstructure of the alloy); 3 - the field of hydrogen damage (typical relief interphased indentations and facets of hydrogenated chipping; negative influence of hydrogen appears in full extent (limited brittlement under predetermined conditions); level of lower plateau (k^H_{th}) determines the efficiency of the alloy under conditions of full development of hydrogen brittlement); 2 - transitional field (micromechanism is not stated; negative influence of hydrogen is shown especially distinct; perhaps the process of fracture has sinergetick character (Malkov A.V. and Kolachev B.A., 1990); characterizes the extent of sensitivity of metal to hydrogen and which may be estimated through the coefficient of sensitivity β_H as k^H_{th}/k^o_{th} (for the alloy AT3≃0,42) (Malkov A.V. and Kolachev B.A., 1984).

One can consider the hydrogen concentration corresponding to the begin field 2, by which change of fracture micromechanism occurs as a critical one and identify with the point of bifurcation (Malkov A.V., 1989). The value of this concentration for the alloy AT3 makes up roughly 0,015% and coresponds after data of concentration (Malkov A.V., 1987) by which titanium hydrides are evolved in the alloy. The fig. 3 may illustrate the negative influence of hydrogen on the survivability. On this figure the dependence of cycles amount on hydrogen content in metal is shown before fracture under the same initial conditions of loading ($k_{max} \simeq 12{,}65$ MPa·$m^{1/2}$). It follows from fig.3 that the raise of hydrogen content in the alloy AT3 from 0,003% up too 0,05% diminishes the survivability of specimen with crack in the order of two, this reduction occuring most intense in the concentrations range of 0,008-0,015% what corresponds to modern rates of hydrogen content in industrial titanium alloys.

One of the advantages of fatigue tests is the ability of determing fracture toughness which in kudrjashov's opinion is an independent criterium of structural strength of materials which characterizes the efficiency (resource) of product under conditions of prolonged cyclical loading and reflects a physical difference of fracture process by statistical and cyclical fracture toughness doesn't depend in practice upon initial conditions of loading and for specimen with the same hydrogen content. The values k_{fc} lie down in sufficiently

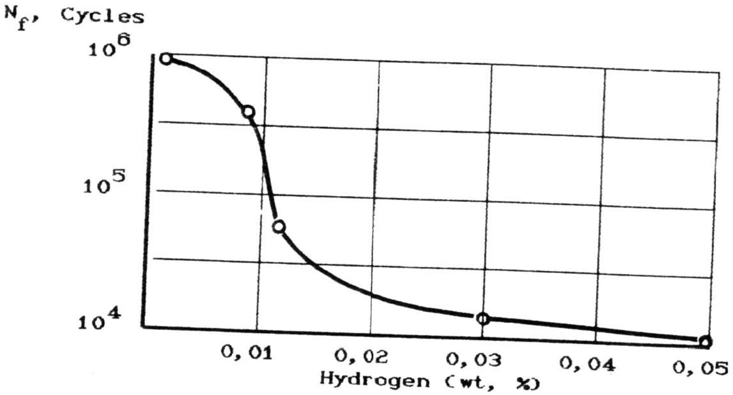

Fig.3. The influence of hydrogen on survivability of specimen with crack from the alloy AT3 by cyclical loading with $k_{max}=12{,}65$ MPa·$m^{1/2}$.

narrow strip of straggling by statistical loading. From the data given on fig.4 it follows that cyclical failure viscosity diminishes with the raise of hydrogen content approaching asymptotically the lower threshold value k_{fch}. k_{fch} - is a

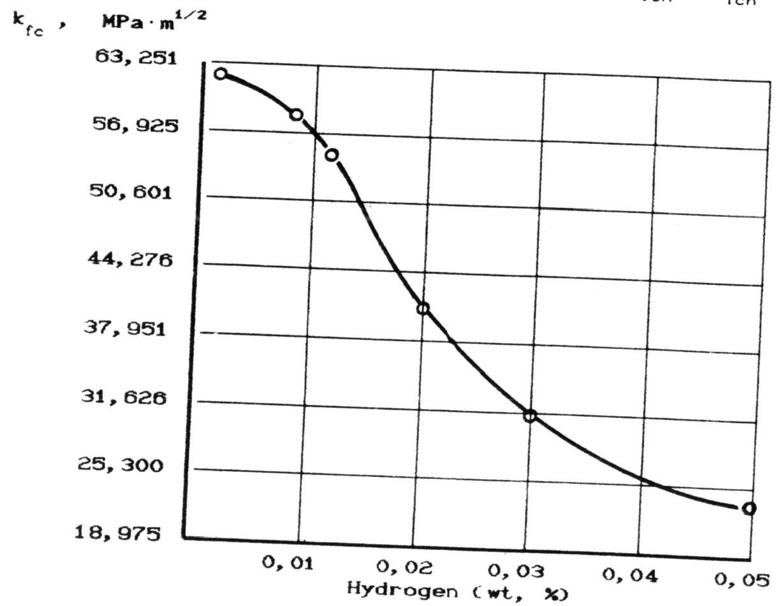

Fig.4. The influence of hydrogen on cyclical fracture toughness of the alloy AT3.

critical stress intensity factor beyoind which the alloy AT3 isn't sensitive in practice to hydrogen by given microstructure type, geometry of specimen and loading conditions. The value k_{fch} compiles for the alloy AT3 about 22 $MPa \cdot m^{1/2}$.

The question about coincidence or close correspondence of k_{fc} with values of k_c or k_{1c} is principal. Those are defined by statistical short-lived tests. The results received in present work showed considerable deviations of k_{fc} from the values of short-crack resistance (table 1).

Table 1. Fracture toughness of the alloy AT3 under conditions of statistical (k_{1c},k_c) and cyclical (k_{fc}) loading.

Hydrogen content (% wt)	k_{1c} $MPa \cdot m^{1/2}$	k_c $MPa \cdot m^{1/2}$	k_{fc} $MPa \cdot m^{1/2}$
0,003	72,890	110,679	62,455
0,008	70,265	101,192	55,339
0,012	61,664	101,192	53,758
0,015	61,664	101,192	49,964
0,02	61,664	101,192	40,477
0,03	53,758	101,192	31,623
0,05	34,785	91,705	23,654
0,1	29,093	84,748	-

In our opinion this difference is connected with following circumstances. By determining k_c during one cycle of loading the specimen are fractured under conditions of common fluidity and slanting fracture is formed. The values k_c are very high what testifies that a considerable part of energy is spended at plastic deformation. Therefore fracture toughness is an integral value in this case which takes into consideration the influence of hydrogen on the processes of plastical deformation and on the process of crack speading. Difference between k_{fc} and k_{1c} is less considerable and may be connected with different type of microstructure and also with the effects of redistribution of hydrogen which take place by relative prolonged cyclical loading.

The modern design principles allow the availability of crackable defects of technological or operation origin in products. Besides in titanium coustructions technological or operation hydrogen alloying is possible and besides hydrogen segregations because it's redistribution in possible fields. On taking into account these circumstances one may consider that to speak about conditions of nonspreading of hydrogen cracks by prolonged cyclical loading is worth after parameters

k_{fch}, k^h_{th} and also by means of analysis of survivability diagrams.

The present work is devoted to the memory of our comrade Kudrjashov Valeri Georgijevitch.

REFERENCES

Ivanova V.S., Kudrjashov V.G.(1970). Method of determing fracture toughness (k_{1c}) after data of fatigue tests of specimen. The problems of strength. Kiev, №3, p.17-19.

Kolachev B.A., Livanov V.A., Buchanova A.A. (1974). Mechanical properties of titanium and it's alloys. Moscow, Metallurgy.

Kolachev B.A.,Malkov A.V.,Sedov V.I. (1975). The use of linear fracture mechanics by studying hydrogen brittlement of titanium alloys. Physical chemical mechanics of materials, Lvov, V.2, №6, p.7-12.

Malkov A.V.,Kolachev B.A. (1976). The influence of hydrogen on fracture energy of titanium alloys. Physics of metals and science of metals, V.42, №2, p.364-371.

Kolachev B.A., Malkov A.V., Kudrjashov V.G.,Sedov V.I. (1982). The influence of hydrogen on fracture toughness of in titanium alloys. In: Titanium alloys with special properties. Moscow, Science, p.115-119.

Kolachev B.A., Malkov A.V. (1983). Physical principles of fracture of titanium. Moscow, Metallurgy.

Kudrjashov V.G. (1985): Determination of mechanical properties. In: Methods of control and research light alloys (Vineblat J.M.). Moscow, Metallurgy, p.275-324.

Malkov A.V., Kolachev B.A. (1979). Methods of estimation of hydrogen influence on service properties of titanium alloys. The problems of strength. Kiev, №1, p.65-71.

Malkov A.V.,Kolachev B.A.,Mishanova M.G. (1982). The influence of hydrogen on fracture mechanism in titanium alloys. Physics of metals and science of metals. Sverdlovsk, V.54, №3, p.617-620.

Malkov A.V., Kolachev B.A. (1984). About criteriums of estimation inclination of metals to hydrogen brittlement. In: Hydrogen in metals. (Kuznetsov V.V.) Permer university, Perm, p.110-114.

Malkov A.V. (1987). Physical nature of hydrogenated brittlement of titanium. News of higher schools. Non-ferrous metallurgy. №1, p.76-81.

Malkov A.V., Mishanova M.G., Alexeev V.K. (1989). Phractographical analysis of bifurkation by hydrogen brittlement of titanium alloys. Problems of sinergetick. (Kuseev I.R.) Ufimer oil institute. Ufa, p.38-40.

Malkov A.V., Kolachev B.A. (1990). Sinergetick of metal fracture by hydrogen brittlement. In: Selforganizing and fractographical structures (Kuseev I.R.). Ufimer oil institute, Ufa, p.15-34.