NEW POSSIBILITIES IN INVESTIGATING FRACTURE OF MATERIALS WITH HYDROGEN

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ABSTRACT

"Proton "Center of Physical-Mechanical Institute has carried out the wide complex of experimental investigation of the strength properties of materials in the hydrogen environment at pressure up to 100 MPa and temperature up to 1000 K. The hydrogen induces localization of damage accumulations and provides the conditions when body strength is determined by the crack behavior.

KEYWORDS

Hydrogen, strength, crack, localization, degradation.

HEADING

As it is generally known, the problem of hydrogen effect and hydrogen containing environments on physical-mechanical properties of metal materials, belongs to the one of the most actual scientific and technical problems. That, on the one hand, can be explained by the fact that physical nature of hydrogen embrittlement of metals has not been discovered completely, what like corrosion of metal materials in many cases is the cause of crashes and great damage to the national economy. On the other hand, because of a number of economic and ecological reasons the hydrogen application in different fields of engineering and industry, on the first place, aircraftspace, nuclear, electronic branches, increases.

The works, connected with the use of hydrogen, are carried out intensively in all technically developed countries and the spectrum of perspective applications is very wide,from new manufactures to the formation of new fields in industry. Here depth oil processing effects (hydro-cracking), incompatible increas of non-inflamable resource efficiency use, hydrogen application in metal treatment (e.g. in stamping) titan alloys (propulsion rocket space systems, including multisystems such as "Shutle","Buran-Energy", works on hydrogen use as aircraft fuel (example TU-155), designs of aerospace aircraft such as "NASP" can be included.

In the nearest future in the world economy considerable increas of hydrogen use is expected. All this evidently makes the problem of creating design materials, capable of working reliably in the given time in the hydrogen containing environments, especially actual. In this connection establishing the character of the change of the physical-mechanical properties of metal material designs, under hydrogen containing environment effect and determining the resource of their durability, are of great scientific and practical interest. Due to the problems of facilitating effect origin and crack increas in metals due to the hydrogen effect, metal brittle destruction phenomena in the hydrogen environment, deserve intensive attention.

Most of accumulated data for previous decades was obtained not by planned investigations but in the course of works stipulated by difficulties appearing in designing and exploitation of concrete products.

Absence of basic notions about mechanism and conformity to natural laws hydrogen degradation dictates the increas of efforts on experimental investigation service properties of materials in hydrogen effect conditions.

Today, in the world, several centers of hydrogen engineering have been formed G.V.Karpenko Physical-Mechanical Institute of the Academy of Science of Ukraine (PhMI) is one of them. The Engineering Center of hydrogen material engineering "Proton" of PhMI became involved in the works on the problems of hydrogen effects on the material behavior almost from the first days of establishing the institute, as soon as hydrogen has been found as a detrement for the design integrity and cause of destructions took place. The first achievements in this field are associated with academician G.V.Karpenko and his school (Karpenko G.V.,1960,1963,1974) and are referred basically to the study of the effect of internal hydrogen and electrolytic hydrogenation on the metals. Further evolution of investigation to some extent was due to the problems of providing the survivability of materials and designs of the rocket engines using the hydrogen fuel, with more emphasis made on the examination of materials affected by gaseous hydrogen environment and nitrogen-hydrogen media within the range of variations of their parameter pressure and temperature (beginning from the cryogenic one) (Tkachev V.I., 1972).

For carrying out the investigation of mechanical properties of metals in the wide ranges of temperatures (2-1073K) and pressures (0.1...100 MPa) of gas alloys in Proton Center the methodology is worked out and a unique laboratory-industrial facilities are created. The complex of methods and laboratory equipment allow to carry out investigations in determining optium conditions of work and choice of materials taking into consideration real conditions of exploitation: - short strength with one axial loading; - short and cyclic strength membrane materials with
two axial loading;

- low-cycle fatigue bending plate specimens;
- high-cycle fatigue with tensile loading;
- high-cycle fatigue bending with rotation;
- resistance of deformation with thermocycling in the ranges of temperatures of 20 - to 2000 K with external loading effect;
- long strength;
- static and cyclic crack grouth resistance;
- tribological crack resistance;
- wide range of structural investigations, including metalgraphycal (optical) electronic microscopy, fractographycal investigations.

X-Ray analysis, permeability, determinate diffusion characteristics of gases in metals, spectral descriptions.

The wide complex of experimental investigations of the strength properties of materials in the hydrogen environment (medium) at pressures up to 100 MPa and temperatures up to 1000 K has been carried out as a result information on the characteristics of short- and longtime strength, fatigue, creep, crack resistance of the structural materials of different of the energetic mechanical engineering, vehicle engines, shipbuilding, aggregates and systems of oil-chemistry and was obtained. Material high temperature, effect of medium ionization on creation of the hydrogen degradation were studied. Other aspects of interaction between hydrogen and metals were investigated, in particular, the effect of hydrogen on the tribological processes and physical- chemical properties of the metal-hydrogen systems. The data of the hydrogen diffusion parameters including the information on the different fields such as electrical, magnetic, temperature and a field of mechanical stresses. Techniques for governing the metal impermeability by means of various effects on their microstructure and surface especially by depositing the diffusional and plasma composition coatings were devised. It should be noted that in PhMI works on the material hydrogen engineering from the very beginning the researches of production of the materials resistant to the hydrogen degradation, protection against the the detrimental hydrogen influence by the mechanical and chemical-thermal treatment of different kinds, and defining the rational operation modes for machines and aggregates with risk of hydrogen degradation. Thus in particular the temperature-force fields for material application in the articles subjected to hydrogen effect were included, the adequate criteria for estimating the metal serviceability in designs and methods for evaluation and prediction of their operation were determind (Tkachev V.I.,1984). Variants for optimizing the chemical composition and structural state of the metal materials were found, a number of new steel and alloy compositions of improved resistance against the hydrogen embrittlement were suggested, promising results concerning the use of super equilibrium nitrogen content in contact with hydrogen were obtained (Tkachev V.I., 1984).

Wide experimental investigations of a large number of the phenomena in metal-hydrogen systems revealed technically promising effect.The effect on processes of the phase transformations of microstructures in alloys, significant acceleration of masstransfer processes (e.g. mutual diffusion of low-mobility fore-nitrogen dopes, etc.) in the materials including the coatings, effects on evolving the inter-metallic phases, possible governing the metal dispersion (powder formation and fragments of the required morphology), promotion of material handling due to the hydrogen effect should be taken into account. (Andreikiv A.E.,1987; Tkachev V.I., 1982, 1990; Pochmursky V.I., 1981, 1987) for example above listed effects,the acceleration of masstransfer in metals under the hydrogen effect suggests the solution of the technological problems of the adhesion in the plasma-deposited coatings (thermoprocessing in hydrogen alloys to improve adhesion in 8 times) and the problems of metal welding diffusion . Effects of this nature are interesting for perfecting the processes of nitriding the hydrogen use (which further is removed from materials). (FedorovV.V., 1988; Svist E.I., 1984). Technological developments were based on the basic effects such as reduction factor (by 20...30% due to the hydrogen effect; including the deformation friction on metal depositing (Tkachev V.I., 1978).; easy cutting and forming of metals. As turned out in this case the positive effect provides hydrogen charging only one instrument being now governed (Tkachev V.I., 1976)

However, the wide experimental data cannot eliminate the necessity of understanding the nature of this phenomenon without which it is impossible to envisage the turns of the evolution in the metal-hydrogen systems or obtain

the optimal solutions including the solutions of the urgent practical problems. Therefore many attempts were to investigate subtle mechanisms predetermining the physical-mechanical properties and behavior of metals under the hydrogen effects and the development of general theoretical conception and quantitative models beginning from the microscopic physical and macroscopic design methods being involved in solution of the engineering problems.

In this case the consideration only of the macroscopic level and phenomenological theoretic model are insufficient for the effective solution of practical problems. Hydrogen effects on the material behavior are generated by processes at the atomic level therefore for achieving the results of general character the "origin" principles should be used as a starting point following their after effects up to the macrostructure level.

Among many originally-induced basic factors the hydrogen degradation is result of the tendency of hydrogen localization in metals. Without it, effects observed in metals with hydrogen concentration of about 1 at H/10 at Me are unlikely to take place in general as well as the fact that with temperature increase even on the hydrogen concentration increase in metal effects of hydrogen embrittlement are weakened. Because of that the hydrogen localization in metals is a factor which makes possible for the serious effects in the materials behavior to appear, even with neglible in the hydrogen concentrations.

Localization factor is connected with two effects varying in their nature.

The first one consists even in the perfect crystal lattice of metal it may be not energetically useful uneven distribution of dissolved hydrogen but presence of lokalizations (clusters) (Goltsov V.A., 1980; Kishi K., 1976). These clusters appear in much the same was as the periodical lattice of proton subsystem (electrons of metal and hydrogen are grouped) which is doped in the metal lattice and whose period has the same value magnitude as the metal lattice parameter has (Kishi K., 1976). The latter means that atomic hydrogen concentration in these phase ...is enriched with hydrogen according to the value magnitude approaches to the unity.

The second effect of hydrogen localization presents its segregation in defects of the crystal structure of the metals (Fojta E.E., 1976; Vavrukh M.V., 1985). The significance of this effect for the material behavior with hydrogen presents results, firstly, from the lattice defects, their structures and properties governing the properties of real materials and, secondly, from defects, were the local concentration of hydrogen exceeds the concentration of hydrogen exeeds the average value for macrobulks in $10^3...10^4$ times and the atomic proportion reaches the ratio 1:1. In these quantities hydrogen in the structure defects may have an appreciable effect on them and thus on the material behavior.

From this, in particular, the important practical conclusion that hydrogen localized in structure deffects really defines material behavior and its integral quantity in metal (macroconcentration) in the general case may not be the comparative hazard measure of hydrogen degradation.

The next key element of the hydrogen metal degradation nature concerns the way of affecting the material behavior by hydrogen in localization cells. A number of theoretical results obtained within the limits of different model presentations convincingly indicate the reduction of adhesion force-decohesion with hydrogen contained in metals such as iron, nickel, ferrum and etc. Though this effect is extremely localized, it creates the preconditions for the unfavorable proceeding the physical-mechanical processes in metals, intensitying the lability of plastic microdeformation and accumulating damages giving them cumulative character.

As regards the solution of the question on the strength design under the hydrogen effect, it would be wrong to apply the traditional criteria of strength against the maximum parameters of stress-deformed conditions whose limit values are determined by the experiments in accordance with the standard.Pprocedures including only the hydrogen effect on the material. The cause of this is that it hydrogen is present the limit state of materials is more responsive to the kind of the stress condition and it is related with processes of hydrogen redistribution in the system during the experimental operation and therefore requires additional provision for compliance of the laboratory experiment with processes taking places in a design.

An exception is cracks growth where self-modelling of the crack top environment which is true also for the processes of interaction with hydrogen makes possible to solve successfully the problems of tests and designs on strength by use of the adequate techniques of destruction mechanics (Tkachev V.I., 1976: Yartis V.A., 1988). In this regards it might be fortunate that hydrogen induces localization of damages accumulations and provides the conditions when bodies strength is determined to a large measure by the behavior of cracks in them.

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