NASA TECH BRIEF

Effects of Hydrogen on Metals

The problem:

To develop a method for minimizing failures in storage tanks and related hardware caused by high-pressure hydrogen effects, the formation of hydrides in titanium, and hydrogen absorption through various metals processing techniques.

The solution:

As yet no general solution has emerged, but much experience in the field and many series of tests have led to development of several rules to guide choice of materials, methods of welding, electroplating, heat treatment, and other processing.

The problem is complicated by the existence of various possible sources (and combinations of sources) of hydrogen. Large quantities of hydrogen may reduce ductility in a metal; accumulations in localized areas may cause internal bursts or blisters. In some circumstances hydrogen reacts with the metal or alloy phases to form brittle compounds resulting in brittle fractures under stresses far below normal.

The hydrides may result from the storage of high-pressure hydrogen, imperfections in the surfaces of metals, use of incorrect weld fillers, inappropriate methods of welding, cleaning, pickling, electroplating, or heat treatment, or original choice of susceptible materials; or from the synergistic effect of two or more of these factors. Clearly some steels are more susceptible than others during fabrication and service. Alpha titanium differs from beta titanium in absorption of hydrogen; use of commercially pure filler wire for welding of Ti-6Al-4V alloy tends to formation of more hydride than does Ti-6Al-4V filler.

When high-pressure hydrogen is present, entry into the metal is possible when molecular hydrogen is dissociated into atomic hydrogen by catalytic reaction with fresh metallic surfaces. Atomic hydrogen may be formed by the localized energy released by micro-cracking or in slippage in the metal; it enters the lattice of the metal, and such entry is strongly influenced by temperature and lattice defects and by metals in the process of transformation or under stress. Such conditions provide the energy necessary for the endothermic process of dissolution of the hydrogen into the metal, either as interstitial solid solution or as metal-hydrogen compounds on the basis of ionic bonding.

Regarding the difference in solubility of hydrogen between alpha and beta titanium, the commercially pure alpha alloy has no stabilizing elements such as the aluminum in Ti-6Al-4V. Aluminum belongs to a group of metals (such as Fe, Cu, Ni, and Mo) in which the hydrogen is endothermically formed and dissolved as interstitial solid solution; while titanium belongs to another group (such as Zr, Ta, and Cb) in which hydrogen occurs in the form of positively charged ions. Conditions causing migration of hydrogen and formation of titanium hydride have not been completely defined, although it is generally accepted that Ti-6Al-4V alloy has sufficient aluminum to provide adequate solubility of hydrogen, and that the small amounts of hydrides formed are inconsequential. Migration mechanisms have been postulated and studied under various influencing conditions, but the triggering circumstances are far from being defined for confident prediction of limiting compositions of alloys, or for design of weld-filler alloys to control such mechanisms.

Regardless of the basic mechanism or mechanisms of metal-hydrogen reaction, applications must be

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cautious. The resistance of one alloy to damage by hydrogen under one set of conditions may not apply under another. Special care is needed where welds are used; new alloys and alloy phases may be formed in weldments that are sensitive to hydrogen; and weldments may entrap pockets or narrow bands of hydrogen concentrations that are not readily detectable and from which hydrogen may diffuse even at relatively low temperatures, so that deterioration becomes time dependent.

Every known method of electroplating produces some degree of hydrogen embrittlement of certain alloys, such as the high-strength steel alloys; chromium plating proved to be the most embrittling in a broad evaluation of methods.

Different alloys seem to differ widely in tolerance of hydrogen without failure. Distribution of hydrogen within a sample is a more important factor in hydrogen embrittlement that is average content of hydrogen.

Note:

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Source: C. E. Cataldo
Marshall Space Flight Center
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