Hydrogen Embrittlement of Metals

Although it is an old problem that has received much attention over the years, hydrogen embrittlement continues to be a problem in the aerospace industry and better quality control is required to minimize its costly effects.

Three forms of hydrogen damage can occur from metal processing: (1) Hydrogen that has been dissolved in the liquid metal subsequently forms H_2 gas pockets in the form of pores and cracks in the solid metal due to the buildup of internal pressure; (2) Hydride phases form inside the metal to embrittle it; (3) Previously absorbed hydrogen in the metal causes crack initiation and growth while the metal structure is under a sustained tensile load. This third form, called hydrogen-assisted cracking (HAC) or hydrogen embrittlement, has been responsible for numerous aerospace failures.

Hydrogen embrittlement has been observed in steels, titanium alloys, aluminum alloys and copper alloys. Failures most often occur in high strength steels because of their low fracture toughness and the high applied stress.

The internal hydrogen originates from metal processing environments such as electroplating, pickling, hydrogen and organic gas heat-treating atmospheres and corrosion reactions. The hydrogen enters the metal in mono-atomic form that is very small and can diffuse through the crystal lattice very rapidly at room temperature. When two atoms of H^+ collect at a discontinuity in the metal (such as a grain boundary, inclusion, dislocations) they form molecular H_2 with a large increase in size and, consequently, a large increase in pressure. When sufficient hydrogen molecules have formed, the internal pressure can become great enough to rupture the metal, even without any additional applied stress. Alternately, this pressure can create many small cracks.

A plastic zone in front of the crack tip normally inhibits the growth of the crack. Hydrogen reacts with the surfaces and defect structure to reduce the effect of the plastic zone and allow the crack to grow. An increase in the hydrogen concentration lowers the required stress for crack growth. HAC mechanisms are complex and not well understood.

Hydrogen embrittlement can be prevented by: (1) avoiding the exposure of metal to hydrogen environments during processing; (2) ensuring that embrittlement relief heat treatments are performed promptly following exposure of hardware to hydrogen; (3) utilizing alloys with high fracture toughness; (4) quality assurance testing of fasteners and metals by means of sustained load test and (5) good metallurgical engineering design practice.
The effects of absorbed hydrogen can be reduced by baking the metal at 190°C for 24 or more hours within 4 hours after exposure to the hydrogen-producing environment. Many aerospace contractors purchase off-the-shelf fasteners and other hardware that are electroplated and which may be embrittled by hydrogen. Everybody should be aware of this problem and should take measures to insure that no such degraded critical hardware is assembled for space flight use.