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Stainless Steel 301 and Inconel 718 Hydrogen Embrittlement

Inconel 718, in the presence of ultrapure hydrogen gas, has a "threshold" pressure (for a given tension and thickness) below which a crack will propagate due to hydrogen embrittlement. A test program was established to (1) determine the maximum safe hydrogen operating pressure for cryogenic pressure vessels made of Inconel 718, and (2) provide definitive information concerning flaw growth characteristics under the most severe conditions of temperature and pressure. Flaw growth characteristics of cryogenically formed stainless steel under similar conditions were also evaluated.

Tensile tests of 26 Inconel 718 and four cryoformed stainless steel specimens were conducted. The specimens were subjected to hydrogen pressures of from 250 to 1000 psi, temperatures ranging from ambient to −100°F, and specimen stress levels of from 22,500 to 120,000 psi. Each specimen was deliberately flawed and then fatigued by cycling until the desired crack growth (approx. 0.060-in. deep) was obtained. To determine crack propagation, test conditions were selected to give maximum flaw growth without failure of the specimen. In an attempt to define the critical areas of flaw growth for a specific application, the test conditions for each sample were based on the performance of the previous specimen.

Using fracture mechanics techniques, the results of these tests may be used to develop the characteristics of flaw growth as a function of exposure time, stress level, gas pressure, environmental temperature and type of material. To provide maximum information for fracture mechanics analysis techniques, a wide range of hydrogen pressures and tensile stresses was used to bracket the areas where flaw growth would occur without specimen failure.

For Inconel 718 welded specimens, the extreme conditions that would permit flaw growth without failure were (1) ambient temperature, 750 psi hydrogen and 67,500 psi for at least 20 hr, and (2) −100°F, 750 psi hydrogen and 67,500 psi for at least 72 hrs.

The extreme conditions for the parent Inconel 718 specimen were (1) ambient temperature, 570 psi hydrogen and 67,500 psi for at least 20 hr, and (2) −100°F, 800 psi hydrogen and 72,000 psi for at least 231 hrs.

The Stainless Steel 301 specimens were all parent metal. The maximum safe condition at ambient temperature was 1000 psi hydrogen and 40, 000 psi for at least 21 hours of exposure. The first Stainless Steel 301 parent metal specimens tested failed on loading at ambient temperature, 1000 psi hydrogen and at 100,000, 60,000 and 50,000 psi stress levels. The specimens that did not fail were "fatigue-marked" before being pulled to failure to permit measuring the crack growth under sustained load.

Conclusions of this test program showed that flaw growth in cryogenic storage system pressure vessels constructed of Inconel 718 or Stainless Steel 301 material in a hydrogen environment is a function of temperature, pressure and stress; that the welded areas of the pressure vessel (welded specimens) have a lower resistance to crack propagation than the parent metal; that the maximum operating pressure which will permit flaw growth without failure is determined by the initial flaw size and the ability to determine the largest flaw size existing in the pressure vessel; and that the extreme conditions for safe extended operation of specific cryogenic storage system pressure vessels are 450 psig at −100°F after a cryo-proof test with liquid nitrogen at 2000 psig.

(continued overleaf)

Note:

Requests for further information may be directed to:

Technology Utilization Officer
Manned Spacecraft Center, Code BM7
Houston, Texas 77058
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Patent status:

No patent action is contemplated by NASA.

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