Fracture Toughness of Al 2195 in a Liquid Hydrogen Environment

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Abstract

Al 2195 has been used to make the space shuttle external tanks (ET) since 1998 according to the ET designs developed with Al 2219. As the Ares program begins to design and test new LOX and LH_2 tanks, more accurate and detailed data on the fracture toughness and behavior of the Al 2195 is needed for engineers to optimize the tank design, minimizing the amount of material used and reducing weight. Different plate gages, weld configurations, and other manufacturing processes such as forging, extrusion, and spin forming will be used in the Ares program and must be characterized. The Hydrogen Testing Facility (HTF) is a unique lab where materials can be mechanically and thermally tested in liquid and gaseous hydrogen environments. At this facility, we are determining the J_{IC} and K_{IC} values for the Al 2195 supply of plate, currently being stored by MSFC. This data will be used to determine what loads can be applied before the material fails. Tests are being carried out in a LH_2 environment to replicate the conditions present in a full tank.

Background

Both J_{Ic} and K_{IC} tests are used to determine a material's ability to resist fracture. The difference between J_{Ic} and K_{IC} tests is that J_{Ic} tests are used for ductile materials while K_{IC} tests are used for brittle materials.

Al 2195 is an aluminum lithium alloy that has become popular for use in cryogenic tanks for aerospace applications. Al 2195 is lightweight and can be friction stir welded fairly easily. Like most materials it becomes stronger when cooled, but unlike most other materials it becomes more ductile at lower temperatures.

The external tank on the space shuttle was originally made of Al 2219. This alloy was used for all the external tanks from 1981 until 1998. Since then all but two of the external tanks used in the shuttle program have been made of Al 2195. NASA plans to continue using Al 2195 for the upper stages of the Ares rockets.

Load frame and test stand after a test in liquid hydrogen.

Procedure

•Samples are cut at various orientations from large plates kept by MSFC for future use in cryogenic tanks for rockets and spacecraft.

•Samples are measured to confirm that they meet test parameters.

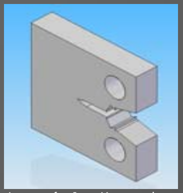


Image of a J_{Ic} or K_{Ic} sample.

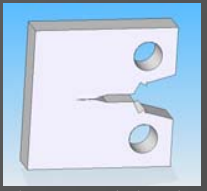


Image of a J_{Ic} or K_{Ic} sample after testing

•A cyclic load is applied to each sample in order to create a precrack at the end of the notch. This precrack will taper off to a very fine point. This tip will mimic the effect of a small flaw within the material during the actual test.

•The length of the precrack is visually verified using a microscope to ensure that testing parameters are met.

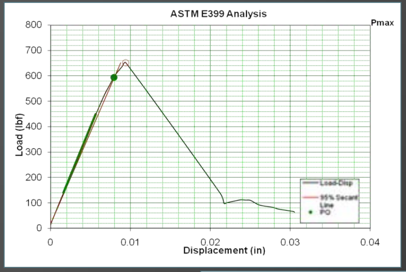
•During the actual test the sample is loaded and unloaded for J_{Ic} tests or pulled at a certain rate (dist/time) for K_{IC} tests. The loads and pulling rates vary during the test based on the loads, the crack length , and pin displacement.

•The crack length is visually confirmed.

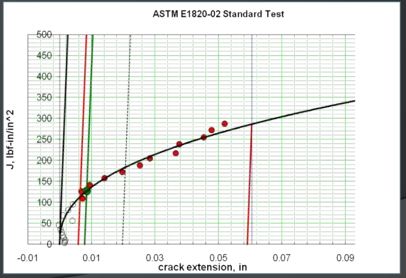
•A marker band is created on the sample by cyclically loading and then ripping it apart. This creates an extension of the crack that will contrast with the crack created during testing.

•The area of the crack surface created during testing is measured visually.

•The data is analyzed to determine the K_{Ic} or J_{Ic} value.



Left: Plot showing how the load varies with displacement during a K_{Ic} test.



Right: Plot showing how the stress intensity factor J varies as the sample is pulled apart during a J_{Ic} test.

The Hydrogen Testing Facility (HTF)

The Hydrogen Testing Facility at Marshal Space Flight Center (MSFC) was established in 1964 for testing metallic and non-metallic materials in LH2 and GH2 environments. This research was critical to the Saturn program which used hydrogen fueled engines on the 2nd and 3rd stages. This facility is equipped with 10 load frames, ranging from 5 to 100 kip (22200 to 444800 N), which are now used to conduct critical tests on materials for the Space Shuttle and Ares programs.

Testing Capabilities

	Gaseous	Cryogenic
Environment	Hydrogen, helium, nitrogen hydrogenated steam, air	Hydrogen, helium, nitrogen
Temperature	-129 to 982 °C (-200 to 1800°F)	-269 to -196 °C (-452 to -321°F)
Pressure	0 to 68,948 kPa (10,000 psi)	2,068 kPa (300psi)

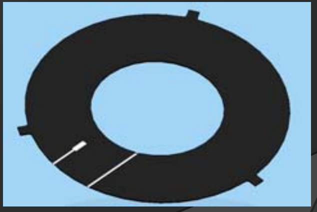
Available Tests

- Exposure
- Tensile / Compression
- J_{Ic} and K_{Ic}
- Creep
- Crack growth
- 3 and 4 point bending
- High/Low cycle fatigue
- Thermal conductivity
- Shear
- Permeability
- Strain to crack
- Other Customized Tests

Other Projects

The properties and service history of a 10,000 gallon liquid oxygen tank were reviewed to determine if the tank was capable of safely storing liquid hydrogen. The tank was found to be acceptable since it was made using metals approved for hydrogen storage and will experience smaller loads storing LH2 than LOX.

A Solid Edge model of a heating plate was created for use in thermal conductivity tests.



Inconel and stainless steel J_{Ic} test samples were prepared for other projects.