

Aluminum to Stainless-Steel Joints for Cryogenic Applications

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Aluminum to stainless-steel joints are necessary for cryogenic applications such as cryogenic fluid management and combustion devices. Supplemental development in this area was required for a test program at NASA Marshall Space Flight Center (MSFC) of an Al6061-RAM2 additively manufacturing liquid rocket nozzle. The test program identified a risk for installing stainless-steel fluid fittings to aluminum manifolds. To address this, a literature search was completed for various joint designs, and three designs were down selected to be cryogenic pressure cycle tested at MSFC. The test pieces were subsequently burst tested with ambient temperature water. This paper provides an overview of the literature review, down selected designs, test setup, test results, and fractography. The test results informed design decisions for the Al6061-RAM2 nozzle, and the recommended design proved to be a robust option with no notable issues identified during hot-fire testing.

I. Introduction

The Reactive Additive Manufacturing for Fourth Industrial Revolution Exploration Systems (RAMFIRE) project matured large-scale lightweight additively manufactured (AM) aluminum [1]. The project focused on printing and hot fire testing an Al6061-RAM2 integral channel-cooled liquid rocket nozzle. Hot fire testing at NASA Marshall Space Flight Center (MSFC) TS115 required stainless-steel facility interfaces. Facility interfaces are needed for coolant inlets, outlets and instrumentation ports. Typically, the interfaces between thrust chamber assembly (TCA) hardware and facility are stainless-steel fittings threaded directly into the hardware or welded stainless-steel tubing to the hardware [2,3]. However, for an aluminum nozzle, those options are not adequate with several associated risks at operating at cryogenic temperatures and high pressures.

To mitigate these risks, a literature search was completed to identify possible options for the aluminum to stainless-steel joint. It was determined that threading the stainless-steel fitting directly into the aluminum manifold could cause thread galling and leakage at the interface. Aluminum tubing that would be welded to the aluminum manifold and later transition to stainless-steel tubing also proved to not to be a viable option. A vendor survey showed that currently available products were not viable due to small internal diameters, thin walls, and strength margins required.

II. Hardware Design

Four test articles were fabricated and tested at MSFC. The four test articles are shown in Figure 1. Test article 1 and 2 are stainless-steel fittings directly threaded into aluminum ports. Test article 3 is a stainless-steel fitting threaded into a stainless-steel flange bolted to an Al6061-T6 flange. The Al6061-T6 flange is welded to a Al6061-T6 base with Al6061-RAM2 filler wire. Test article 4 is explosively bonded Inconel 625 to Al6061-T6 with a tantalum interlayer. The stainless-steel fitting is threaded into the Inconel 625 and the Al6061-T6 portion of the explosively bonded stock is welded to a Al6061-T6 base with Al6061-RAM2 filler wire.

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Figure 1. Test fixtures tested for aluminium to stainless-steel joints [1].

III. Testing

A. Test Setup

Testing was performed at the NASA MSFC Component Development Area (CDA). The test series started with pressure cycle testing with liquid nitrogen, the test schematic is shown in Figure 2. The test series used a 100-gallon run tank rated up to 5,000 psig. Relief valve RV-1, set at 1,800 psig, was used to protect the test equipment from overpressure. RV-2 and RV-3, also set at 1,800 psig, were used for thermal relief. Liquid nitrogen was supplied to fill the run tank and to submerge the test articles. The pressure cycle test setup is shown in Figure 3.

Data Acquisition (DAQ) included a Dewesoft X3 software package designed to control the Krypton 6xSTG Data Acquisition Hardware. This software operated and controlled a 6 channel DAQ module that allows for both strain measurements and temperature measurements. LabView 2018 professional development software was used to operate and control National Instruments modules connected to a 14 slot NI-9179 dDAQ Chassis.

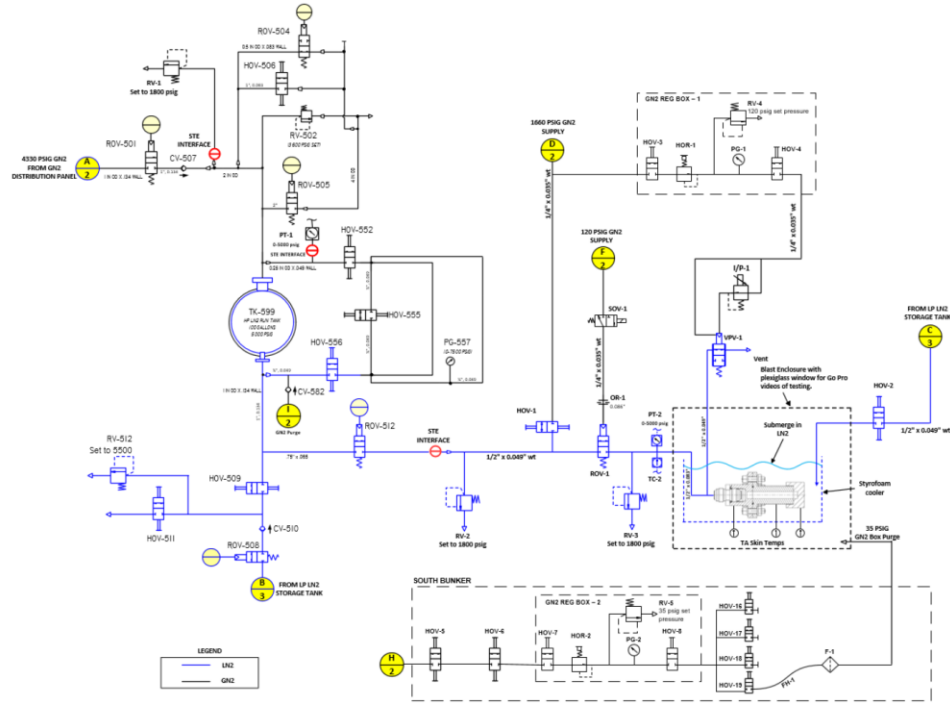


Figure 2. Cryogenic pressure cycle test schematic.



Figure 3. Cryogenic pressure cycle test setup

B. Test Results

All articles were tested to a minimum of 20 cycles, with each cycle holding the test article at 9.0 MPa (1,300 psi) for 5 seconds and 10.8 MPa (1,560 psi) for 15 seconds. After the cryogenic pressure cycling, the articles were burst test with ambient temperature water. The number of cycles that the samples were tested to and burst pressure for each test fixture is shown in Table 1.

Table 1. Pressure cycle and burst testing results for port development [1].

Test Article #	Description	# of Cycles	Burst Pressure	
			[MPa]	[psig]
1	Aluminum Threads	30	132.3	19,193
2	Aluminum Threads	23	146.4	21,228
3	Bolted Flange	24	56.1	8,142
4	Explosively Bonded	22	46.5	6,745

While test articles 1 and 2 did have significantly higher burst pressures than test articles 3 and 4, the aluminium threads presented unacceptable risk for continued re-use from engine dynamics. If the threads galled, the hardware would be compromised. It is important to note that the stainless-steel fitting was only torqued once into the fixture; even low-cycle retightening would cause a sharp decline in thread strength (fatigue). The other two test articles burst at the weld seam, which was expected. The burst pressures were both significantly higher than the operating pressure of the nozzle. Of the two, test article 4 was selected due to reduced part count and fewer leak paths.

C. Fractography & Metallography

The weld crack for test article 4 is shown in Figure 4. A cross-section of the galled threads for test articles 1 and 2 are shown in Figure 5.

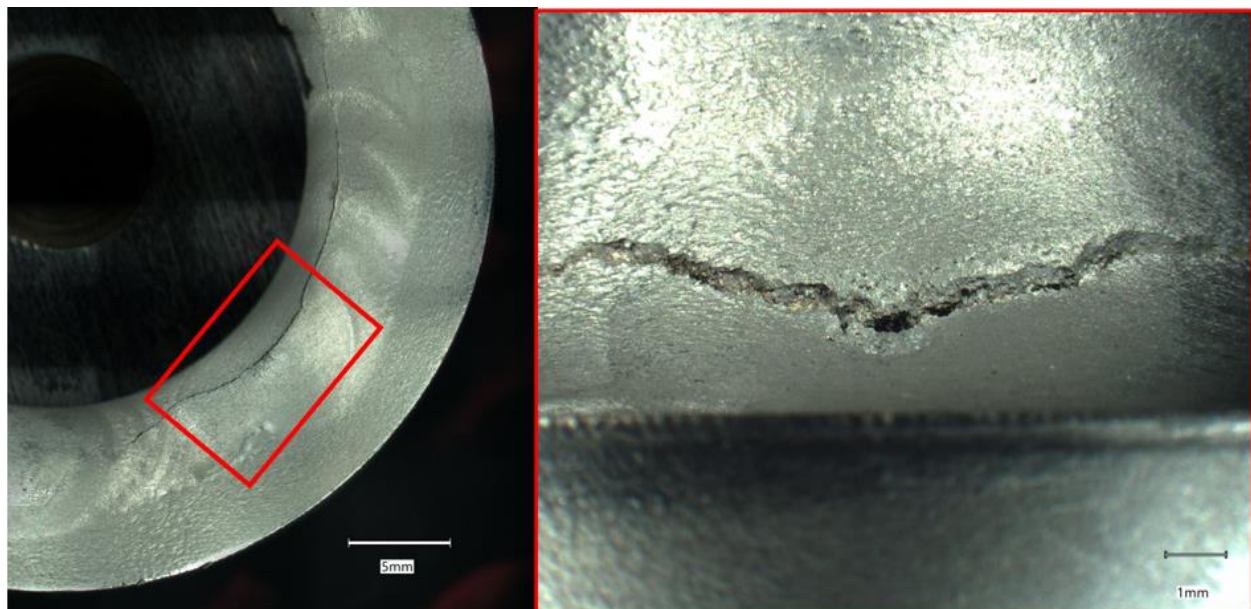


Figure 4. Test article 4 weld initiation & completion site. Possible site of crack initiation.

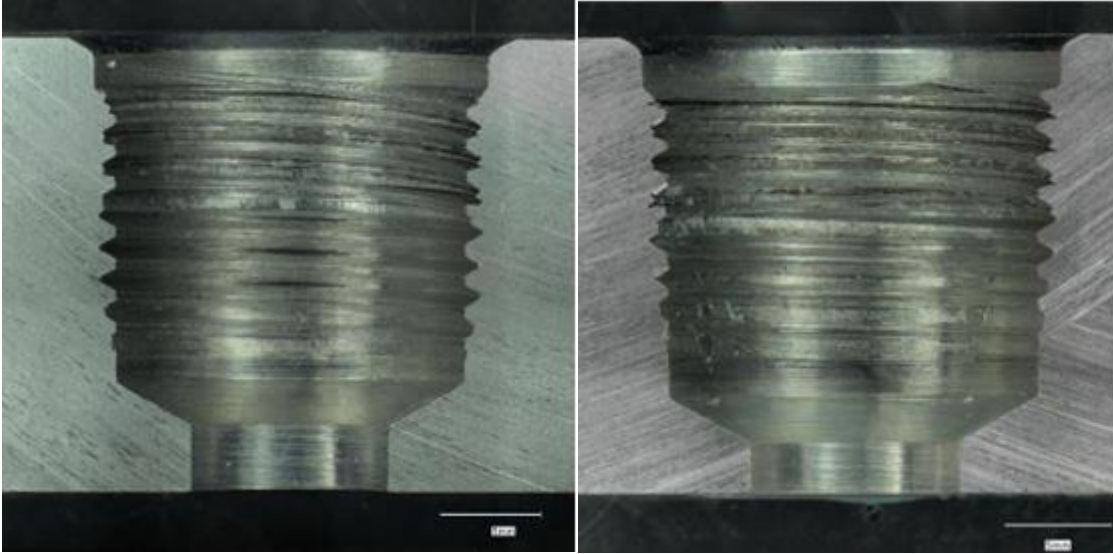


Figure 5. Cross section of galled threads from test articles 1 & 2.

IV. Conclusions

V. Acknowledgements

VI. References

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