Evaluation of Cryogenic CFRP Tank Elements under Pressurized Liquid Hydrogen

Makoto YOSHIDA, Takayuki SUDO, and Masataka NOSAKA, Rocket Propulsion Research Division, E-mail: yoshida@kakuda-splab.go.jp

Keywords: RLV, Cryogenic Tank, CFRP, Liquid Hydrogen, Acoustic Emission, Helium Leak

1. Introduction
To realize a fully reusable Single-Stage-To-Orbit (SSTO) transportation system, rocket engine performance must be greatly increased and total weight must be drastically reduced. To reduce the weight of the cryogenic tanks which occupy most of the dry weight of the system, it is effective to use lightweight composite materials such as carbon fiber reinforced plastic (CFRP). The goal of the present study was to reduce the weight of the propellant feed system (cryogenic tanks, turbopumps, feed lines and valves) by using lightweight materials such as CFRP. We manufactured cylindrical cryogenic tank elements with thin walls and flanges and conducted pressurized tests under conditions of cryogenic temperature with liquid nitrogen (LN₂) and liquid hydrogen (LH₂) up to 2 MPa.

2. Test Piece
Figure 1 shows the appearance of the cylindrical test piece having a diameter of 100 mm and with flanges made of CFRP. The material is satin-woven carbon fiber cloth with a toughened epoxy. The cylindrical part is 4-layer angle ply (0F/45F/-45F/90F) with a thickness of 1.6 mm, constructed by a hand-layup method; the flanges are integral with the cylinder. Designed pressure was 0.6 MPa.

3. Cryogenic Pressurized Test
Figure 2 shows the apparatus employed in the cryogenic pressurized test. The test piece was placed inside a protective chamber to prevent hydrogen-related accidents. The hydrogen gas concentration around the test piece was monitored by a hydrogen gas detector to detect any abrupt leakages. The inside pressure and temperature, strain and temperature of the cylinder wall, and displacement of the bottom flange and AE were measured to monitor the deformation of the test piece and detect signs of collapse. AE sensors were attached to stainless rods, with a diameter of 4 mm and a length of 150 mm, to prevent a temperature drop of the sensors which may vary their sensitivity.

Tests were conducted in stages: pressurization by room-temperature gas hydrogen, by cryogenic LN₂, and then by cryogenic LH₂. Prior to the tests and after each test, helium leakage was measured at room temperature. To prevent unnecessary changes of the setup, a helium leakage test was conducted by pressurizing the protective chamber with helium gas at 0.35 MPa, vacuuming the inside of the test piece, and measuring leakage by a helium leak detector.

4. Results and Discussion
Figure 3 shows the pressurized test results with LH₂ up to 2 MPa. The test piece was pressurized at 1.0, 1.5 and 2.0 MPa in stages, the pressure at 2.0 MPa being maintained for about one hour. During the test with LH₂, the protective chamber was purged with nitrogen gas to prevent explosion, causing the surface of the test piece to be wet with liquid nitrogen; and wall temperature showed the melting point of nitrogen (63 K). Hoop stress and strain at 2 MPa are about 63 MPa and 800 respectively. AE count data showed some peaks during the operation of applying and reducing pressure. These peaks may correspond to the boiling of...
LH₂; almost no AE was measured during the stable pressure condition. No sign of collapse was observed in strain, AE and other signals, and hydrogen was never detected inside the protective chamber. After a series of tests, no critical damage was observed by visual observation.

Helium leakage was measured before the series of tests and after each test at room temperature. In each test, helium leakage was measured for more than 100 hours since the main reason for leakage is diffusion of helium molecules in the material. Figure 4 shows helium leakage test results. The leakage values prior to a series of tests until after LN₂ pressurized tests showed no remarkable change; after the LH₂ pressurized test, however, the leakage value approximately doubled ($1.0 \times 10^{-10}$ m³/m²/sec at 70 hours).

Figure 5 shows stable values of the helium leakage tests. In two cases which drew in right half of the figure, the test piece was pressurized by helium gas at 0.35 MPa and only the cylinder was wrapped with thick resin film; this resin film was then vacu-umed and the leakage was measured. Results showed no remarkable difference between the two conditions and it was concluded that the cylindrical part was sound and that the thickened parts near the flanges may have been damaged.

5. Concluding Remarks
A cylindrical test piece 100 mm in diameter and with flanges made of CFRP was pressurized with LH₂ up to 2 MPa for about one hour and no sign of collapse was observed in strain, AE and other measured data nor by visual observation, and hydrogen was never detected inside the protective chamber.

Helium leakage of the whole test piece approximately doubled in the LH₂ pressurized test, but the cylindrical part was proved to be sound. This finding shows the possibility of small damage to the thickened parts near the flanges.

References
3) Robinson, M.J.; Composite Structures on The DC-XA Reusable Launch Vehicle, 28th International SAMPE Technical Conference (1996)