§2. Thermal Stress Calculation of FIREX Target under Cryogenic Environment

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A typical FIREX target consists of a plastic shell with 500 μm in diameter, a gold cone guide and a glass fill tube. Each part is glued together by an epoxy resin for both structural rigidity and gas leak tightness. Liquid fuel is supplied in the shell though the fill tube, and then it is solidified. A thin layer of solid fuel with ~20 μm in thickness is required to be formed on the inner surface of the shell. The developing cone guide heating technique would realize the specification of a fuel layer.

To date, several 500 μm PS shell targets have been ready for the fuel layering demonstration. However, they have not survived a cooling down process yet and have been ruptured. Different thermal contractions of the composing materials might result in exceeding the fracture stress during cool down. To discuss on mechanical issues of an assembled FIERX target under cryogenic environment, the thermal contraction and stress are estimated.

Fig. 1 shows the two dimensional axisymmetric model of the FIREX target which has the same configuration with the ruptured target. The fill tube, however, is disregarded for model simplification. The shell and cone guide are glued by an epoxy which is covered on by an epoxy fillet. Its radius is varied from 5 to 100 μm to estimate how the fillet works to keep the target validity. For each component, various thermal contraction coefficients with temperature dependence are considered. Material properties at cryogenic environment are shown in Table 1. Poisson's ratios without temperature dependence are assumed to be 0.34, 0.34 and 0.44 for PS, epoxy and gold, respectively. Cool down from 293 K to 10 K is simulated and consequent thermal stress on the target was calculated by the ANSYS code. The point of the cone tip is restricted onto the origin as a constraint.

Table 1 Material properties for calculation.

	Thermal contraction $-\Delta L/L_0$ (293 – 4.2 K) [%]	Fracture stress [MPa]
PS	1.5	79 (at 4.2 K)
Epoxy	1.1	150 (at 4.2 K)
Gold	0.32	~200 (at 293 K)

The calculation of total equivalent stress as thermal stress after cooling down with the 5 μm fillet radius is represented in Fig. 2. The area exceeding the PS fracture stress is shown in the figure. For the fillet radius of 5 to 100 μm, the maximum stress for each material is evaluated at 120-140 MPa in the PS shell, at 120-178 MPa in the gold cone and at ~120 MPa in the epoxy fillet. According to these calculations, along the glued boundary between the cone and the PS shell, the maximum stress in the PS shell is predicted to exceed its fracture stress without fillet radius dependence. It is supposed that the crack would initiate from the PS shell and cone guide boundary, and then the epoxy fillet can prevent to rupture if it has an enough radius for PS shell reinforcement. For example, in the case of a 5 μm radius, the fillet does not cover the area under its fracture stress.

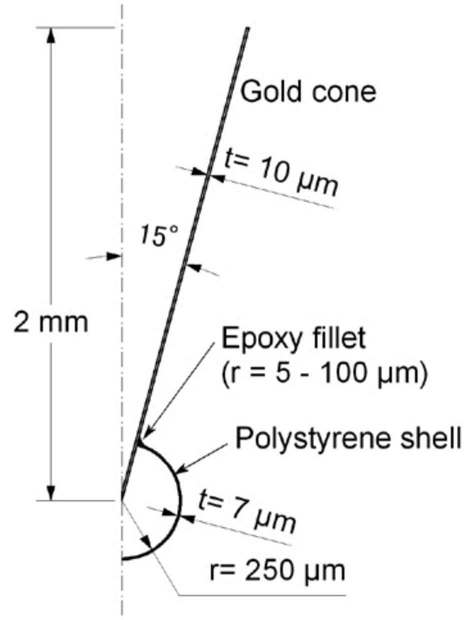

Fig. 1. Calculation model of FIREX target.

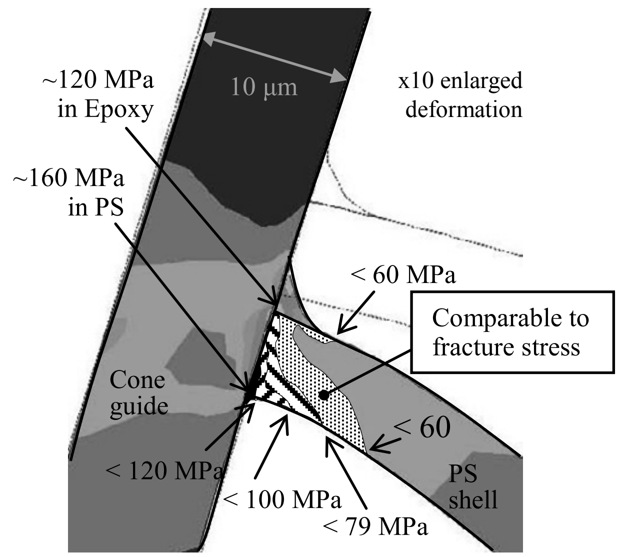

Fig. 2. Thermal stress from cooling down to 10 K. Fillet radius = 5 μm.