

Study on the MOX Fuel Manufacture Glovebox Containment for Earthquakes -Deformation and Leakage Tests for Window Panels-

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1 ABSTRACT

This paper shows the results of the leakage tests and the large deformation analysis of a full-scale glovebox window to establish the capacity of the containment of the MOX fuel manufacturing glovebox during an earthquake.

In leakage tests, the stainless steel container installed on the reverse of the glovebox window was pressurized with a halogen-air mixture after deformation was applied to the upper part of window frame using micro handy jacks, and to the four glove-ports using electrical actuators.

A numerical model for the rubber seal was obtained with biaxial loading tests of chloroprene sheet specimens. Tensile loading tests of acrylic resin specimens were conducted to measure the material modulus. The FEM code ABAQUS was applied to the numerical simulation and the user-subroutine function for the hyperelastic model was used to predict the deformation of the rubber seal.

These tests demonstrated that a glovebox window constructed with a rubber seal and a resin panel shows no leakage larger than 0.1vol%/h with large static deformation. The results of the numerical simulation showed that the rubber seal resolved the effects of deformation of a window panel on the containment barrier, and that two lips of the rubber seal play a key role on the containment of the glovebox.

2 INTRODUCTION

The purpose of this study is to qualify the confinement of a glovebox window designed for a commercial mixed oxide (MOX) fuel processing facility in Japan.

For MOX fuel processing facilities, the glovebox is used as the primary containment boundary for the release of plutonium (Figure 1). The glovebox consists of a stainless steel cabinet and the glovebox windows. One glovebox window consists of glove-ports, chloroprene rubber gasket, a transparent resin panel, and stainless steel retainer parts bolted to the cabinet.

Gloveboxes normally have some amount of leakage when subjected to pressure differences. In Japan Industrial Standards: JIS Z 4820 (2002), the standard for a glovebox where a radioactive substance is processed in a nuclear fuel facility is a leak rate of less than 0.1vol%/h for dry operation by negative pressure from 500Pa to 700Pa.

However, the leakage rate that the Japanese standard demands is normal for the glovebox, and it is necessary, in order to secure the safety of mixed oxide fuel processing facilities, to evaluate the confinement performance of the glovebox during earthquakes.

Miura et al. (1995, 2003) showed the results of shaking-table tests and leakage tests using a full-scale glovebox. In those studies, no leakage of inner gas was observed due to S1 and S2 seismic motions.

Leakage was considered to have occurred when a rubber gasket came out of contact with the window panel or the glovebox cabinet. The motion caused by an earthquake has the potential to separate the surface of the gasket from other surfaces. However, the deformations of glovebox components resulting from the shaking-table tests were considered small to evaluate for their leak mechanism. Moreover, the dynamic response would be related to the conditions surrounding a seismic event and the glovebox design.

Hargett (1995) showed static deformation test results and leak rates for laminated glass panels with neoprene rubber gaskets. In that study, a laminated glass panel cracked due to static deformation. However, the MOX fuel processing facilities in Japan will implement resin panels.

Therefore, this paper discusses deformation and leak test results for full-scaled glovebox window made of acrylic and polycarbonate resin in order to evaluate fundamental leak data of glovebox windows. Moreover, numerical results provided by the finite element method (FEM) are given to describe the confinement mechanism.

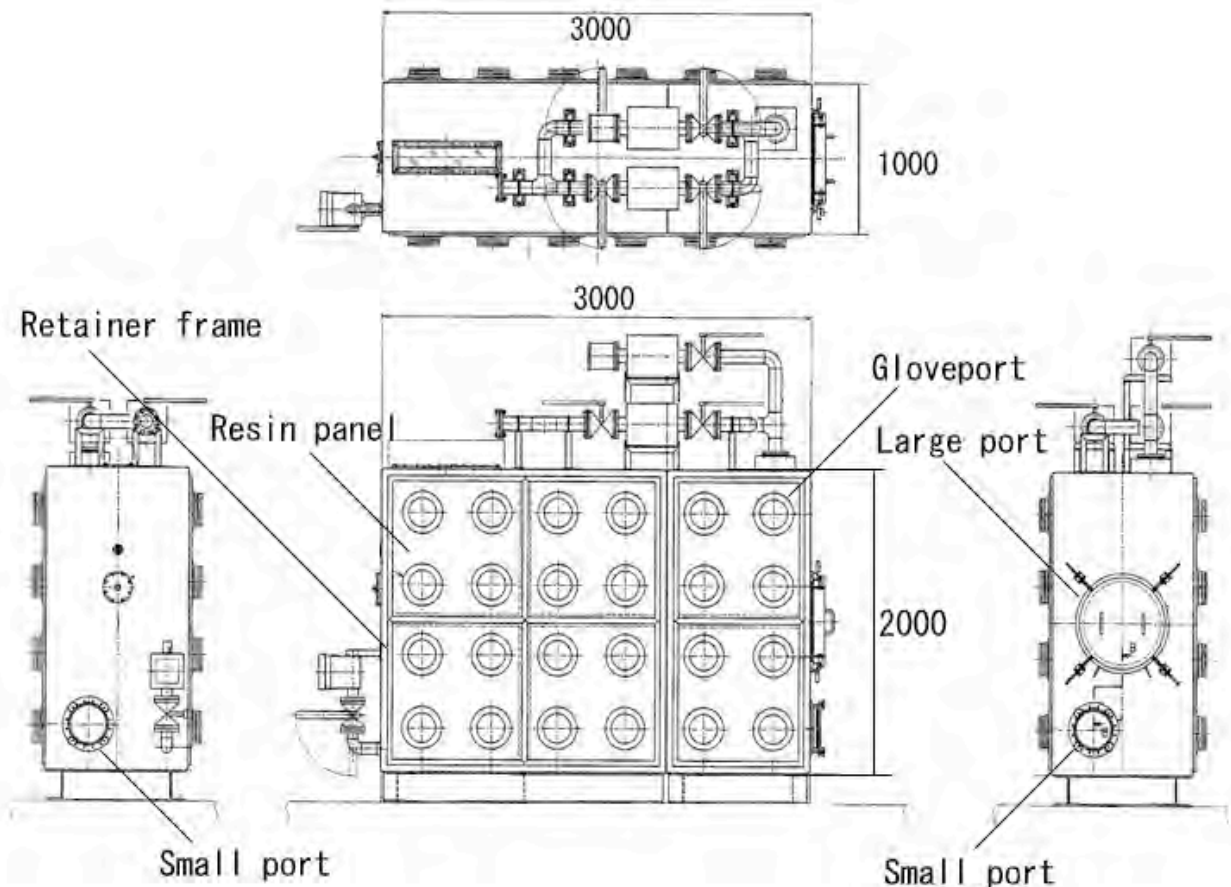


Figure 1 Small model of MOX fuel processing glovebox (Capacity: 6m³)

3 DEFORMATION AND LEAKAGE TEST OF GLOVEBOX WINDOWS

Figure 2 shows the test specimen of a glovebox window. The panel is made of acrylic and polycarbonate resin, and is 926 mm wide, 966 mm high, and 10 mm thick. For the evaluation of leakage rate, a stainless steel container with a capacity of 37.4 L was installed on the back of the specimens to evaluate the leakage rate from the confinement boundary. The edge of the panel was covered with a chloroprene rubber seal.

The acrylic or the polycarbonate resin panes were fixed in place by the stainless steel retainer frames which were bolted to the stainless steel frame (12 mm thick, and 80mm wide) to imitate the glovebox cabinet beam.

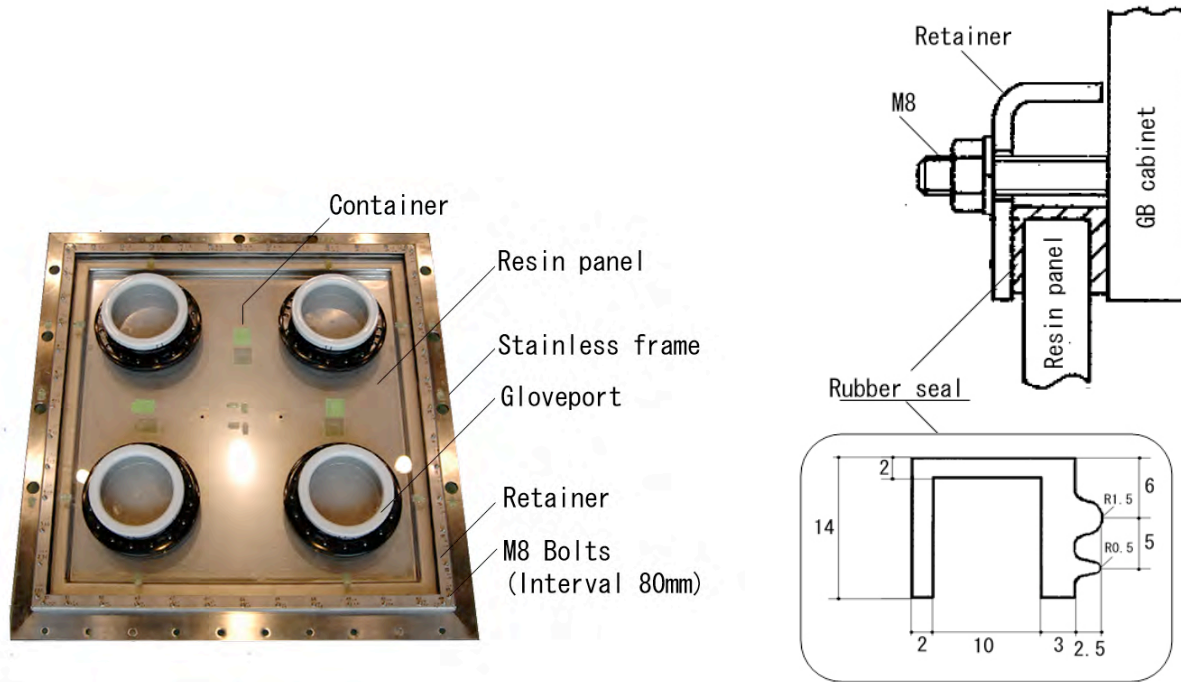


Figure 2 Test specimen of glovebox window and chloroprene rubber seal

3.1 TEST CONDITIONS

In order to establish the capacity of the containment barrier, the leakage tests were conducted on test specimens that deformed statically. Two kinds of static deformation were applied to the specimens. The first deformation was applied evenly to the glove-ports using four electric actuators (Figure 3). Another deformation was applied to the upper part of the frame with six handy micro jacks.

Table 1 shows the combination of the deformation applied to the frame and the glove-ports. Displacement of the panel and the frame was measured with laser displacement sensors.

Leakage rates were evaluated while deformation of frame and glove-ports was maintained. The leak rate at the positive pressure differential, was calculated using the following equation:

$$L_A = \frac{60}{t} \left\{ \frac{(P_g - P'_g) - (P_A / T_g) T_g - T'_g - (P_A - P'_A)}{P_A} \right\} \times 100 \quad (1)$$

Here, L_A is leakage rate (vol%/h), P_g is the inner pressure of the specimen, and P_A is atmospheric pressure. The notation (') indicates the passage of time t (min). For the leakage rate given by equation 1, it is necessary to assume the capacity of the glovebox.

Therefore, we assumed that 1 m³ of volume was confined by one full-scale window. The leakage rate was calculated at about 800 Pa of positive pressure differentials. When the 37.4L sealed container is pressurized 800 Pa, 0.295L of gas is sent to it as follows:

$$\begin{aligned}\Delta V &= 37.4 \left(\frac{101,325 + 800}{101,325} - 1.0 \right) \\ &= 0.295 (L)\end{aligned}\quad (2).$$

Also, the pressure differential in a minute at the leakage rate of 0.1 vol%/h is calculated with the following equation in consideration of the volume of the sealed container and the assumed volume of 1m³ to be confined.

$$\begin{aligned}\Delta P &= 0.1(\text{vol\%/h}) \times 101,325(\text{Pa}) \\ &\quad \times \frac{1,000L}{37.4L} \frac{1}{60(m)} \frac{1}{100(\%)} \\ &= 45.1(\text{Pa})\end{aligned}\quad (3)$$

Therefore, the relationships between the differential pressure and time are calculated by:

$$\begin{aligned}\Delta V &= C \frac{(P_n - 101,325)}{101,325} \Delta t \\ V_{n+1} &= V_n - \Delta V \\ P_{n+1} &= 101,325 \left(\frac{V_{n+1}}{37.4} - 1 \right) \\ t_{n+1} &= t_n + \Delta t\end{aligned}\quad (4)$$

Were, C is the conductance of the specimen. The modified pressure differential D_p' was given as follows:

$$D_p' = D_p - (P_A^{init} - P_A) + (P_A + 800) \frac{T_C^{init} - T_C}{273 + T_C^{init}} \quad (5)$$

Here, D_p is the observed pressure difference between the inner of specimen and the atmosphere, T_C is the inner temperature of the specimen, and T_C^{init} is the initial temperature. In the leakage test, the pressure differential was observed for 25 minutes.

3.2 LEAKAGE TEST RESULTS

Frame and panel deformations (see Table 1) were applied to the test specimen, and the pressure differential, temperature and atmospheric pressure were measured.

The test results under the deformation mode-1 and mode-2 condition with acrylic resin panels are shown in Figure 4 and 5, respectively. The pressure differential lines assumed the leak rate as 0.1 vol%/h and 0.05 vol%/h for 1m³, were also plotted in the figure using equation 4. If the observed pressure difference was plotted under the lines, the deformed specimen shows the greater leakage than the 0.1 vol%/h or 0.05vol%/h. In these cases, the pressure differential was maintained flatly and significant leakage was not observed. The differential pressure of the leakage test with polycarbonate panel under the deformation mode-1 and 2 was maintained like the case with an acrylic panel, and the leakage was not admitted.

The test results under the deformation mode-3 condition with acrylic and polycarbonate resin panels are shown in Figures 6 and 7. The relationships between the pressure differential and the time were shown in Figure 6(b) and 7(b). In these results, -40mm displacement was applied to the glove-ports. Under these condition, no leakage was observed, even when both swaying deformation to the frame and spheroidal deformation to the window panel were applied to the specimens. A halogen leakage detector was also

applied to check for small leakage. Neither damage to the resin panel nor leakage greater than the standard was observed.

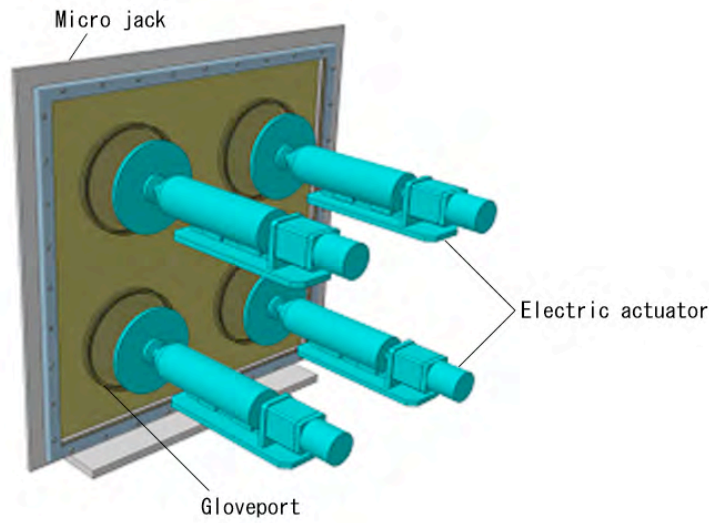
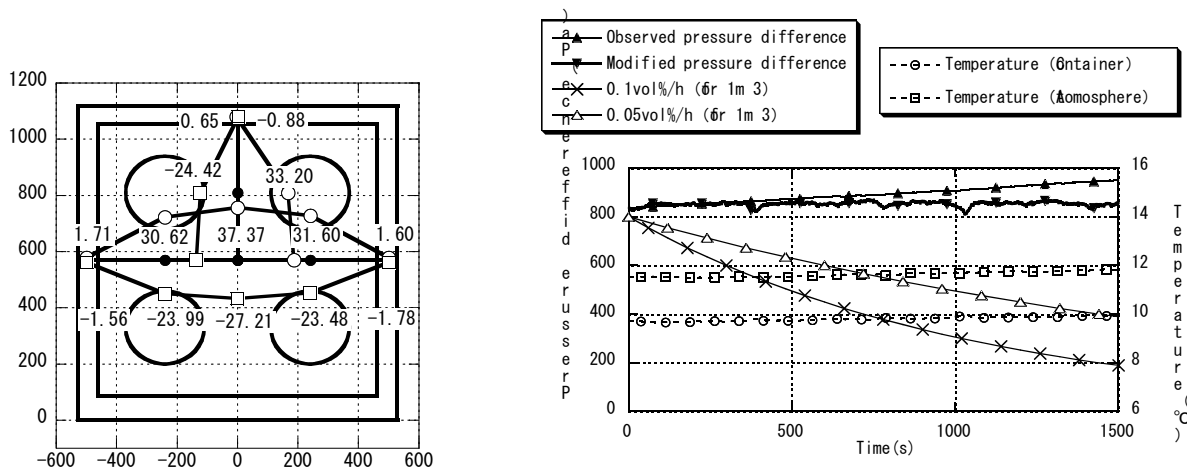


Figure 3 Glovebox window specimen and electric actuator

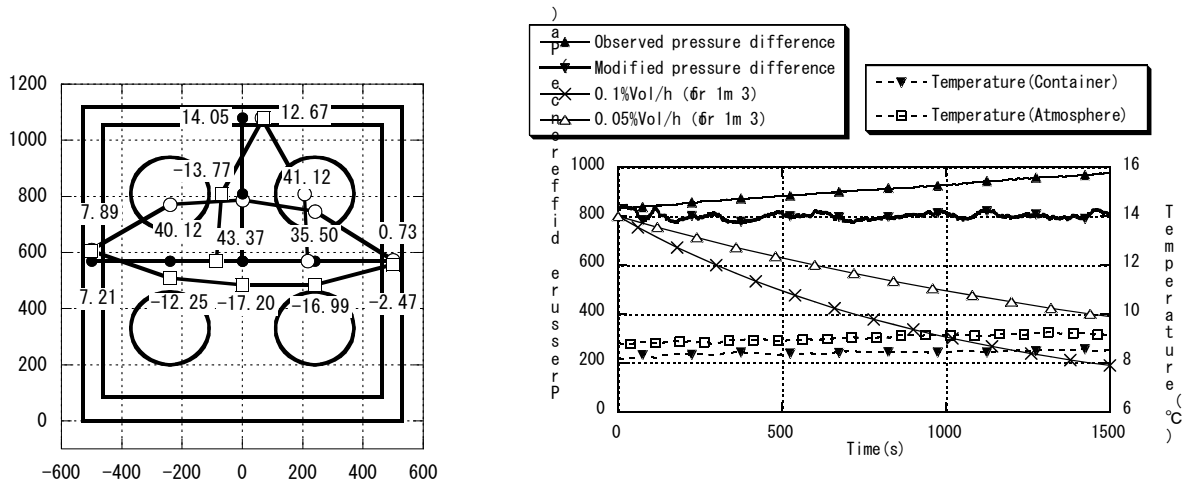
Table 1 Conditions of loading test for glovebox window specimen

Mode 1	Mode 2	Mode 3
Glove-ports: $\pm 20\text{mm}$	Glove-ports $\pm 20\text{mm}$	Glove-ports $-30,-40\text{mm}$
<p>Fixed</p> <p>$\pm 20\text{mm}$</p>	<p>25mm</p> <p>$\pm 20\text{mm}$</p>	<p>25mm</p> <p>$-30\text{mm}, -40\text{mm}$</p>
Displacement of upper frame		
	<p>25 20 15 10 5 0</p>	<p>25 25 25 25 25 25</p>



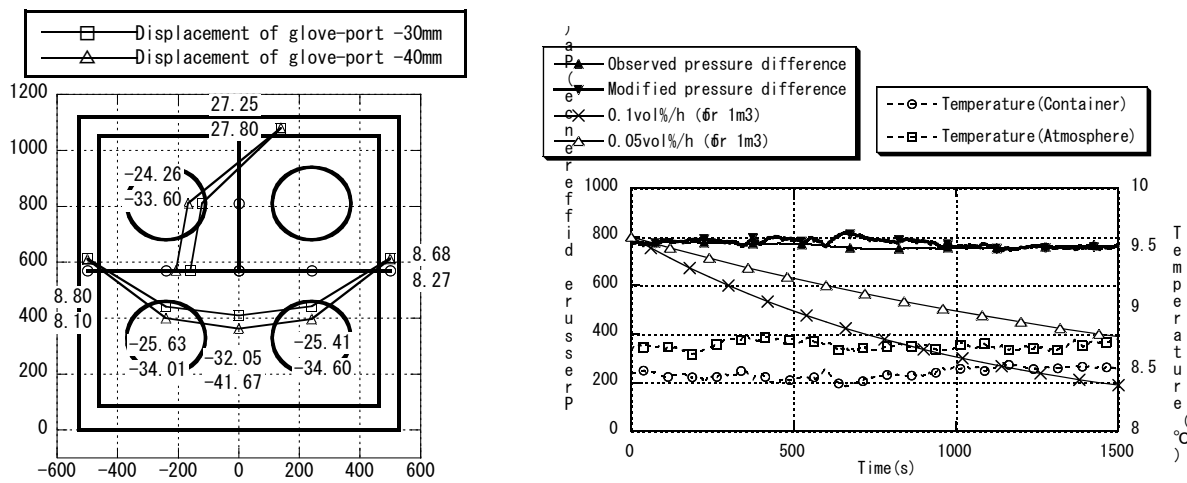
(a) Deformation of acrylic panel (b) Relationships between pressure difference and time of leakage test

Figure 4 Results of loading test and leakage test of acrylic panel window (Mode-1)



(a) Deformation of acrylic panel (b) Relationships between pressure difference and time of leakage test

Figure 5 Results of loading test and leakage test of acrylic panel window (Mode-2)



(a) Deformation of acrylic panel (b) Relationships between pressure difference and time of leakage test

Figure 6 Results of loading test and leakage test of acrylic panel window (Mode-3)

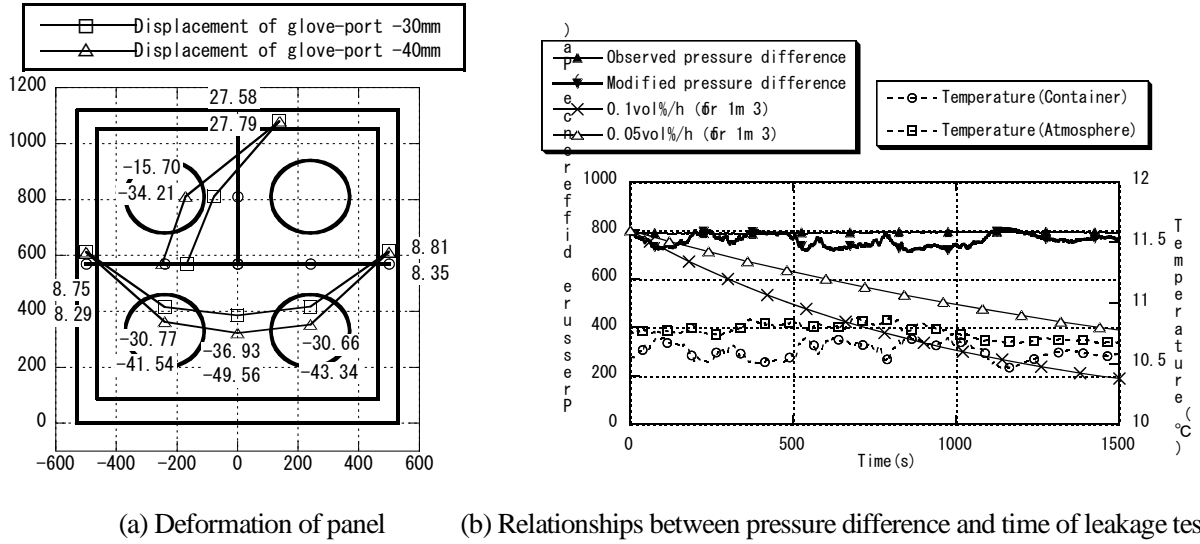


Figure 7 Results of loading test and leakage test of polycarbonate panel window (Mode-3)

4 FINITE ELEMENT ANALYSIS

4.1 Material modelling of rubber seal

Numerical simulations using 2-dimensional finite element analysis were conducted to evaluate sealing mechanism of glovebox acrylic window. The hyperelastic model was applied to material modelling of chloroprene rubber seal and the elasto-plastic solid model was applied to the acrylic panel. The 2nd Piola-Kichhoff stress S of the hyperelastic model is given as:

$$S = 2 \frac{\partial W}{\partial I_1} \frac{\partial I_1}{\partial C} + 2 \frac{\partial W}{\partial I_2} \frac{\partial I_2}{\partial C} + JpC^{-1} \quad (6)$$

Where, W is the elastic potential function, J is the determinant of the deformation gradient tensor F , C is the Right-Green deformation tensor, p is the hydrostatic pressure, I_1 and I_2 are the first and second invariants of the Right-Green deformation tensor, respectively. The material behavior of the hyperelastic material was defined by the elastic potential function W . The following type of functions was applied to the modelling (Seki et al. 1987, Fukahori et al. 1993).

$$\frac{\partial W}{\partial I_i} = C_{i1} + C_{i2}(I_i - 3) + C_{i3}(I_i - 3)^2 + C_{i4} \exp\{C_{i5}(I_i - 3)\} \quad (7)$$

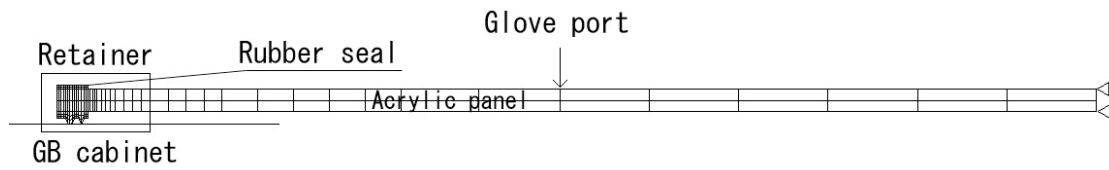
Material modulus C_{ij} were obtained by bi-axial loading test of chloroprene rubber sheets as follows:

$$\begin{aligned} \frac{\partial W}{\partial I_1} &= 0.414 - 0.137(I_1 - 3) + 0.172(I_1 - 3)^2 + 35.1 \exp\{-58.4(I_1 - 3)\} \\ \frac{\partial W}{\partial I_2} &= 0.515 - 0.301(I_2 - 3) + 0.0577(I_2 - 3)^2 - 34.2 \exp\{-57.4(I_2 - 3)\} \end{aligned} \quad (8)$$

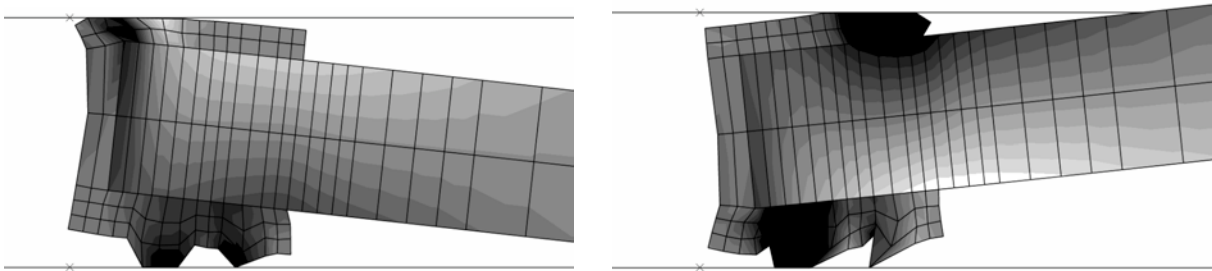
For the material modulus of acrylic resin, the Young's modulus, the Poisson's ratio and the yield strain were set to 3,000MPa, 0.33 and 2% by tensile loading tests, respectively.

The 2-dimensional model for finite element analysis is shown in Figure 8(a). The boundary conditions for the numerical simulation, 8.75N as the bolt's force was applied to the top of rubber seal. Afterwards, +20 mm and -20 mm of displacement were applied to the glove-port position. The contact boundary condition was applied to the retainer frame. The static friction coefficient between rubber seal and retainer frame, was assumed as 0.8. The deformations and mean stress distributions calculated using ABAQUS are shown in Figure 8(b). In the figure, the mean stress distribution in the range of $\pm 1\text{MPa}$ is displayed by light and shade. The rubber seal placed between the acrylic panel and the glovebox frame is deformed greatly from the result of the numerical simulations, and it can be considered that behavior that two lips played alike to the pinned support for the deformation of the window panel.

Moreover, the relationships between the load of the rubber seal, the retainer frame and the glove-port displacement is shown in Figure 9. It is understood that the load of the lip maintain constantly, and the retainer side vary greatly. This was caused by the higher stiffness of retainer-side than the lip-side.



(a) 2-dimensional FEM model of rubber seal and acrylic panel



(b) Deformation and stress contribution of rubber seal and acrylic panel ($\pm 20\text{mm}$)

Figure 8 Results of numerical simulation of rubber seal and acrylic panel

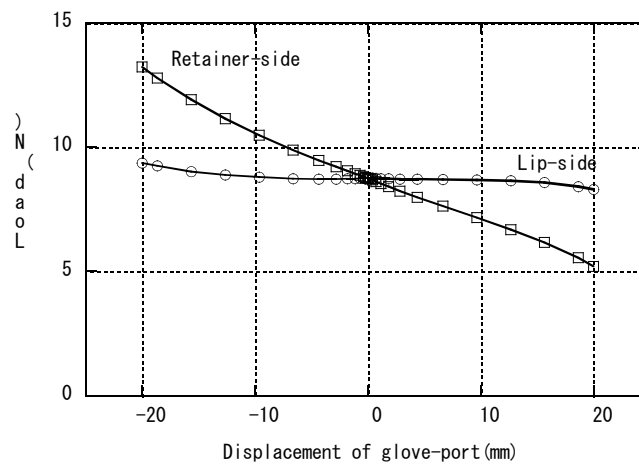


Figure 9 Relationships between load of rubber seal and displacement of glove-port

5 CONCLUSION

In order to obtain the judgement data related to the confinement capacity of the MOX fuel processing glovebox, the static loading and leakage tests for glovebox window specimens were conducted. The sealing behavior by rubber seal, retainer frame and acrylic panel was simulated numerically. The results can be summarized as follows:

In deformation and leakage tests, 3-modes of deformations were applied to the frame and glove ports. Neither damage to the resin panel nor leakage greater than the standard was observed in any of the examination cases.

From numerical simulation, it is observed that the rubber seal follow the resin panel flexibly and the double lip accomplished the key role to the confinement capability.

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