INFLUENCE OF MECHANICAL VIBRATION IN TRANSPORT ON LEAK-TIGHTNESS OF METAL GASKET IN TRANSPORT/STORAGE CASK FOR SPENT NUCLEAR FUEL

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ABSTRACT

Mechanical vibration in sea transport of spent fuel shipping cask has been measured and analyzed to result in possible cyclic displacement of ±0.02 mm to the metal gasket. In order to obtain a relationship between amount of lateral sliding of the lid and the leak rate, a 1/10-scale model of a lid structure of metal cask with a metal gasket of double O-ring type was manufactured. The gasket had a diameter of 10 mm and was coated with aluminum sheet. The metal gasket was thermally aged simulating heat from spent fuel in the cask. Static one-directional loading experiments showed no leakage when the lateral displacement was less than 0.1 mm. When the displacement increased up to 3 mm, the leak rate increased up to 10^{-6} Pa·m^3/sec, but recovered to 10^{-8} Pa·m^3/sec in 72 hours. Cyclic loading experiments showed the leak rate did not increase permanently when the lateral displacement was within ±0.02 mm. The leak rate increased permanently, when the displacement increased to more than ±0.035 mm.

Dynamic one-directional loading experiments showed that the leak rate after the maximum displacement coincided with that at the same displacement by the static one-directional loading experiments. Namely, the leak rate did not depend on the loading rate nor displacement rate.

These results indicate that the mechanical vibration in transport would influence the leak-tightness of the metal gasket required for storage if the amplitude of the vibration exceeded a threshold value.

Key Words: metal gasket, leak-tightness, transport/storage cask, mechanical vibration, containment

INTRODUCTION

Transport casks of spent nuclear fuel will receive mechanical vibration during transport. It has been known that the containment performance of metal gaskets is influenced by large external load or displacement [1]. Quantitative influence of such vibration during transport on the containment performance of the metal gasket has not been known, but is crucial information particularly if the cask is stored as it is after the transport.

The purpose of this paper is to quantify influence of mechanical vibration during transport of transport/storage cask with metal gasket on the performance during storage. In order to obtain a relationship between amount of lateral sliding of the lid and the leak rate, a 1/10-scale model of a lid structure of metal cask with a metal gasket of double O-ring type was manufactured. The metal gasket was thermally aged simulating heat from spent fuel in the cask. Static one-directional loading experiments showed that when the displacement increased up to 3 mm, the leak rate increased up to 10^{-6} Pa·m^3/sec, but recovered to 10^{-8} Pa·m^3/sec in 72 hours. Cyclic loading experiments showed the leak rate increased permanently, when the displacement increased to more than ±0.035 mm. Dynamic one-directional loading experiments showed that the leak rate did not depend on the loading rate nor displacement rate. These results indicate that the mechanical vibration in transport would influence the leak-tightness of the metal gasket required for storage if the amplitude of the vibration exceeded a threshold value.

METHOD

Experimental Apparatus and Specimen

In order to obtain a relationship between the amount of lateral sliding (displacement) of the lid and the leak rate, a 1/10-scale model of a lid structure of metal cask with a metal gasket of double O-ring type was fabricated and assembled as shown in Figure 1. The gasket had a diameter of 10 mm and was coated with aluminum sheet. The scale model consists of three flanges bolted together and helium gas was installed in a groove of one of the outer flanges. The surface roughness was Ra=0.8.

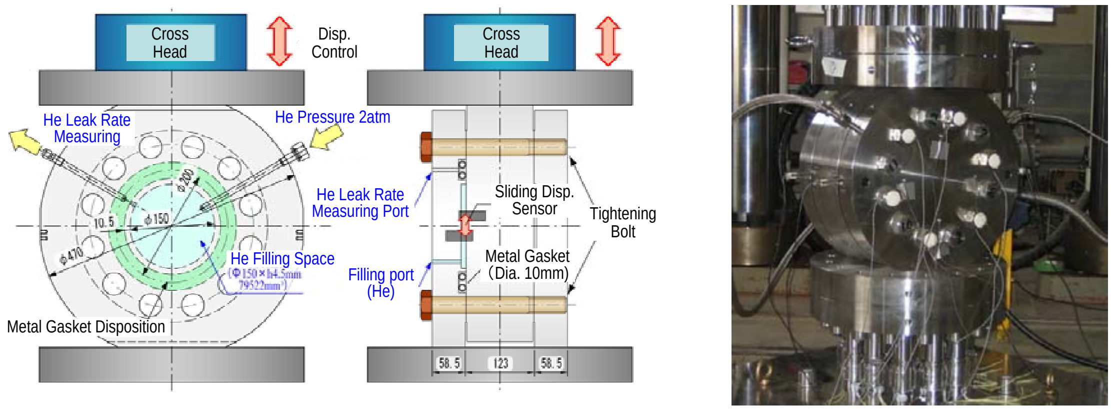


Figure 1. Scale model of a lid structure of metal cask with a metal

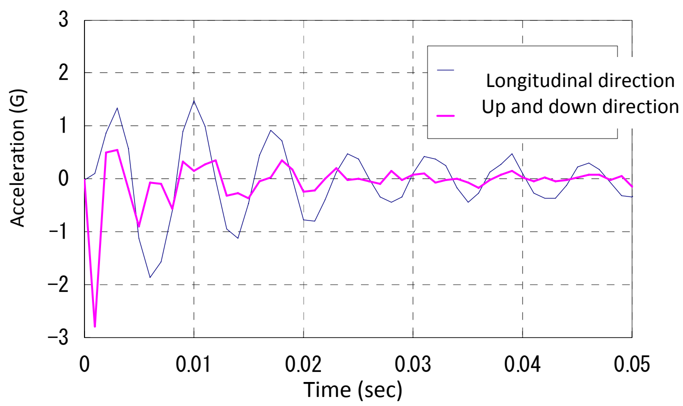


Figure 2. Time history of acceleration measured at a trunnion supports of the spent fuel shipping cask transport frame

In this test, 2 atm (gauge pressure) of helium gas was filled in the space between the flanges. Eddy current displacement sensors (accuracy of ±0.01 mm) were used to measure displacement of the flanges. Sliding load and relative displacements were applied to the middle flange using loading test equipment. In order to simulate the thermal ageing effect of the metal gasket due to the heat from spent fuel loaded inside the cask, the flanges with the metal gasket were heated for 20 hours at 180 °C inside an oven prior to the tests. The temperature and the time conditions were assumed to simulate the heat history of the gasket after spent fuel loading before transport, with the aid of Larson Miller Parameter equation. Instantaneous leak rates were quantitatively measured at the lid by the helium leak detector. The leak rate and change of axial force of the bolts in the lid flange were measured with elapsed time.

Experimental Conditions

Mechanical vibration during sea transport of spent fuel shipping cask has been measured and reported by Shirai, et al [2]. They obtained a time history of acceleration measured at a trunnion supports of the spent fuel shipping cask transport frame as shown in Figure 2.

Using the history of the acceleration, they also calculated a time history of a lateral sliding of the secondary lid of a transport/storage metal cask for spent fuel as shown in Figure 3. Based on their results, cyclic displacement of ± 0.02 mm was assumed for vibration during sea transport and given to a cask flange model as described above. Due to the constraint of the experimental apparatus's ability, the loading speed was 0.01 mm/s and the frequency of the vibration was 0.125 Hz. The experiments were carried out three times for each condition.

Furthermore, in order to confirm the effect of loading speed and the effect of cyclic loading, three kinds of conditions were developed and the experiments were carried out as shown in Table 1.

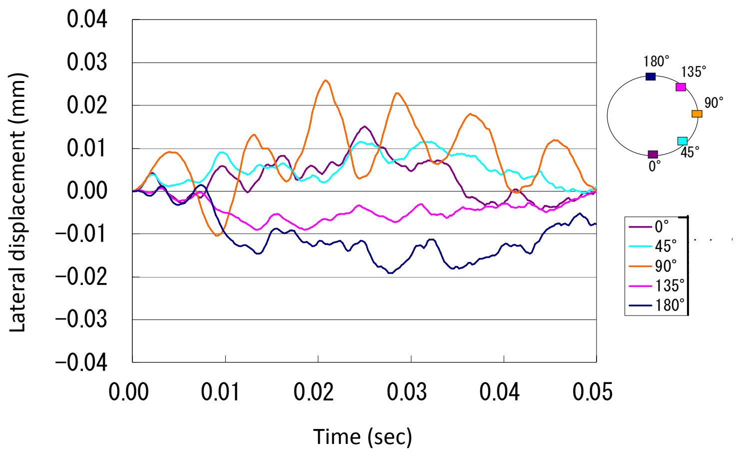
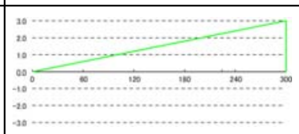
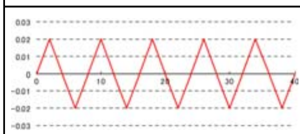


Figure 3. Time history of a lateral sliding of the secondary lid of a transport/storage metal cask for spent fuel

Table 1. Experimental conditions

Conditions	Displacement	Speed	Heat load	Pattern of given displacement	Test number
(1) Static, one-direction-al loading	3mm	0.01mm/s	Equivalent heat before storage LMP=6930 (180℃×20hr)		No.1 :SSS70011 No.2 :SSS70012 No.3 :SSS70013
(2) Cyclic loading	±0.02 mm	0.01mm/s			No.1 :SRL3010011 No.2 :SRL3010012 No.3 :SRL3010013
(3) Dynamic, one-direction-al loading	3mm	85mm/s			No.1 :SSS80011 No.2 :SSS80012 No.3 :SSS80013

Set-up of Initial Condition

In this experiment, it is important to investigate the influence of the lateral sliding displacement of the cask lid flange with the metal gasket on the leak rate of the gasket. In order to prevent from difficulty of giving continuous and various sliding motions between the metal gasket and the lid flange in the experimental apparatus, the initial condition of the experimental apparatus and specimen were set-up as shown in Figure 5. Namely, to avoid flange contact the bolt force was relaxed for the amount of the decrease of the tensile force due to the creep deformation of the gasket by the heat from the spent fuel installed to the cask before transport as shown in Figure 6.

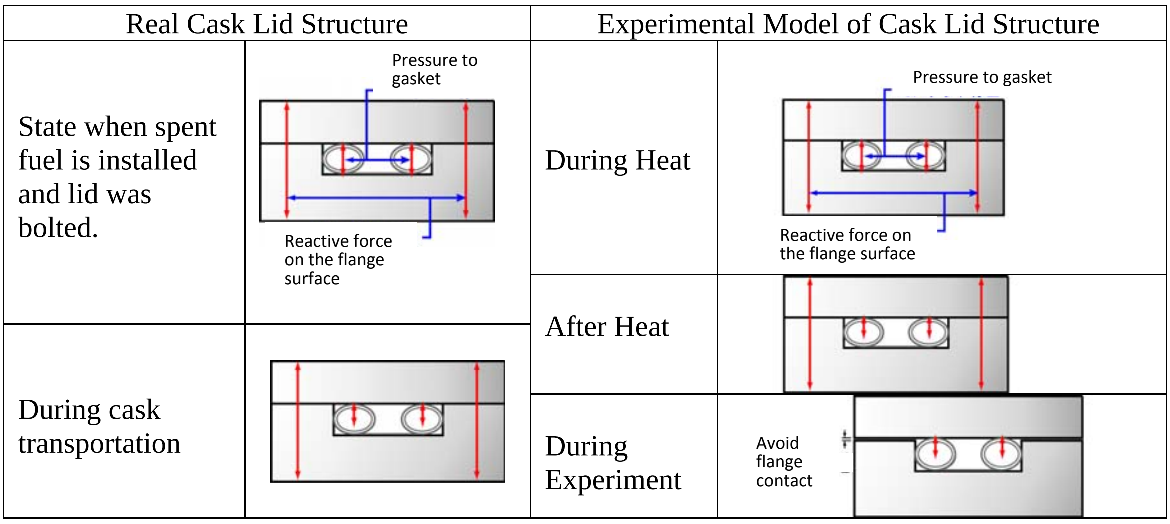


Figure 5. Status of containment boundary of real cask and experimental model

Figure 6 shows change of tensile force in bolts with elapsed time. The line from (a) to (b) shows the increase of tensile force in the bolts by tightening the bolts in the lid flange with the metal gasket. The line from (c) to (d) shows decrease (relaxation) of the tensile force due to the creep deformation of the gasket by the heat from the spent fuel installed to the cask before transport. The horizontal broken line shows the tensile force in bolts recommended by gasket supplier. The point (e) shows tensile force at this experiment.

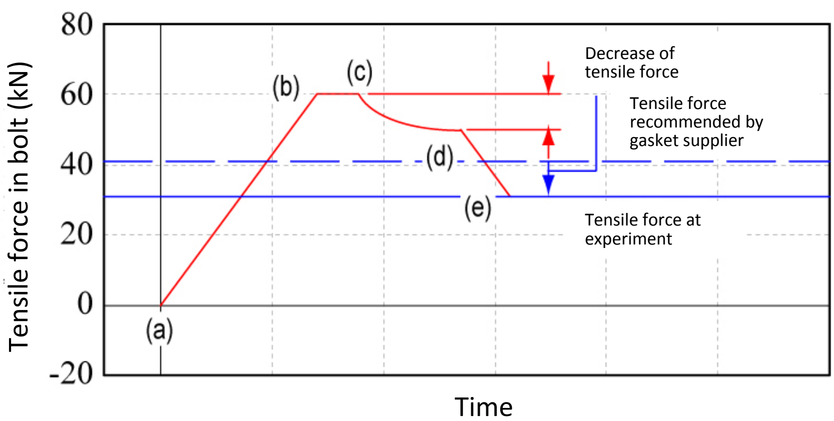


Figure 6. Change of Tensile Force in Bolts with Elapsed Time

RESULTS

Static and one-directional loading

Figure 7 shows leak rate measurements as a function of radial displacement of the flange with the gasket. If the displacement is less than 0.1 mm, no leakage was found. When the displacement increased up to 3 mm, the leak rate reached to about 1x10-6 Pa·m^3/sec. During the displacement increase, the tensile force in bolts decreased a little, but not significantly.

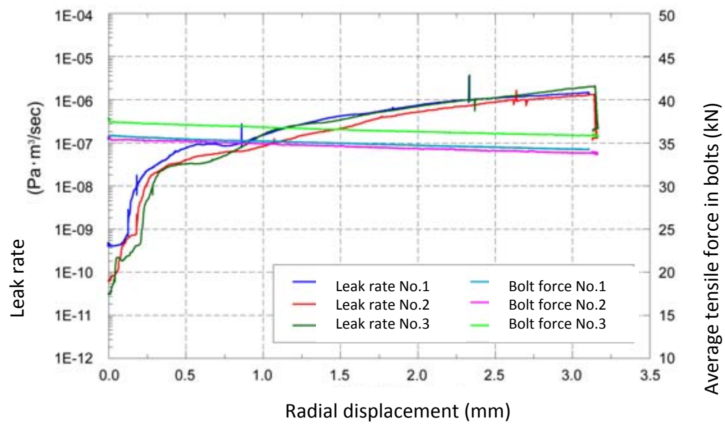


Figure 7. Leak rate with radial displacement

Figure 8 shows leak rate change with time after the static and one-directional displacement experiments. The leak rate was 1x10-6 Pa·m^3/sec after the experiments, but recovered up to 1x10-8 Pa·m^3/sec.

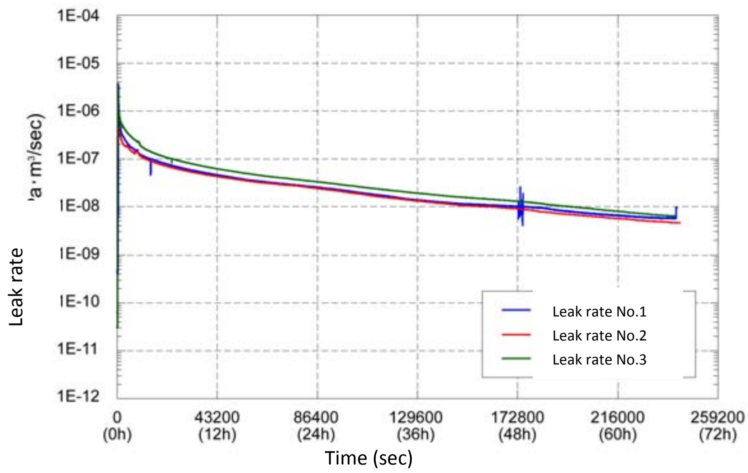


Figure 8. Leak rate with time under static and one-directional displacement loading

Cyclic loading

The frequency of the cyclic displacement experiment was 0.125 Hz and the nominal displacement was ± 0.02 mm. Figure 9-a shows a representative result showing leak rate and displacement as a function of time. The initial leak rate was 1x10^{-10} Pam^3/sec. The leakage started when the radial displacement exceeded ± 0.022 mm and increased as the displacement increased. When the cyclic displacement stopped, the leak rate recovered until the initial leak rate if the cyclic displacement was less than ± 0.025 mm. The leak rate did not recover to the initial leak rate if the cyclic displacement was more than ± 0.035 mm. Nevertheless, the leak rate is still less than 1x10^{-8} Pam^3/sec. Corresponding leak rate of a full-scale cask lid model would be less than 1x10^{-7} Pam^3/sec taking account of the scale factor [3].

On the other hand, a decrease of the axial force of the bolts was also observed during the vibration, which might have contributed to the increase of the leak rate as shown in Figure 9-b.

Dynamic and one-directional loading

Based on a result of a free drop test of a full-scale cask and the experimental apparatus ability in this study, the loading speed was set as 85 mm/s.

Figures 10-a and 10-b show leak rate, radial displacement, and average bolt force as a function of time. The radial displacement increased instantaneously up to 3 mm as the leak rate increased up to $1x10^{-6}$ Pa·m^3/sec. Figure 10-b shows a decrease of the average bolt force at the time of the leakage increase. The leak rate measurements were continued and recovered up to $1x10^{-8}$ Pa·m^3/sec after 72 hours..

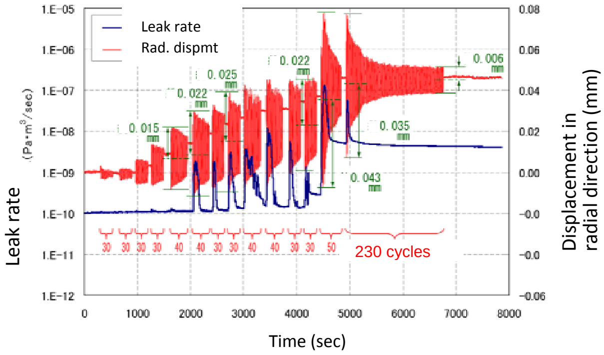


Figure 9-a. Measurements of leak rate and radial displacement with elapsed time under cyclic loading

SUMMARY AND DISCUSSION

The static one-directional static loading experiments showed that no leakage was observed if the displacement was as small as 0.1 mm. When the displacement increased up to 3 mm, the leak rate increased up to 10^{-6}Pa·m^3/sec, but recovered up to 10^{-8} Pa·m^3/sec after 72 hours.

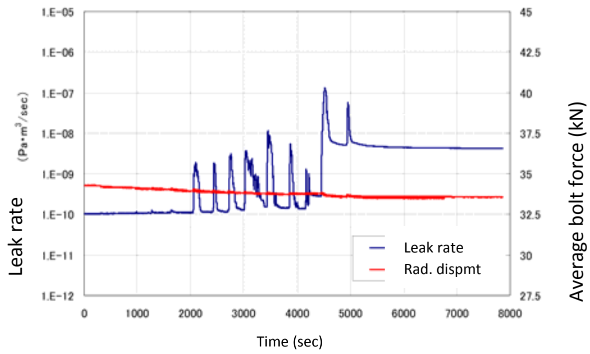


Figure 9-b. Measurements of leak rate and average axial bolts force with elapsed time under cyclic loading

The cyclic loading experiments showed the leak rate did not increase permanently if the displacement was within ±0.02 mm.

The dynamic loading experiments showed that the leak rate after the maximum displacement coincided with the leak rate at the same displacement by the static and one-directional loading experiments. The leak rate did not depend on the loading rate or displacement rate.

CONCLUSION

Mechanical vibration in transport would influence the containment performance of the metal gasket for storage if the amount of sliding exceeded a threshold value. A further research will be required on the mechanism of the leakage.

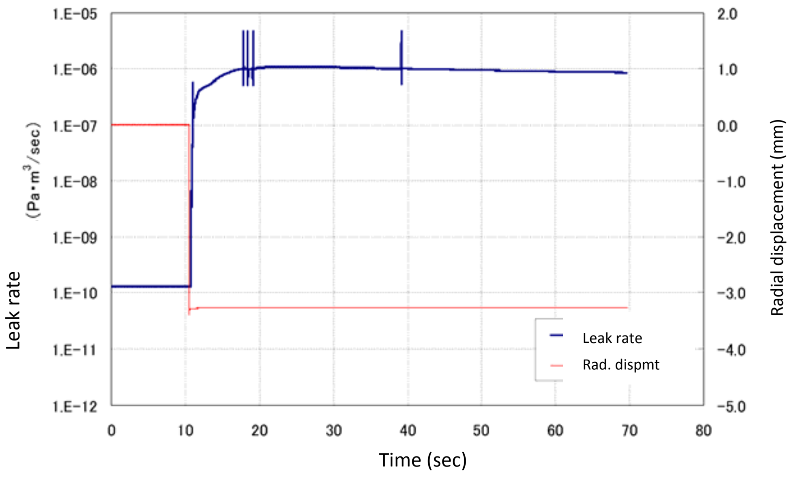


Figure 10-a. Leak rate and radial displacement as a function of time

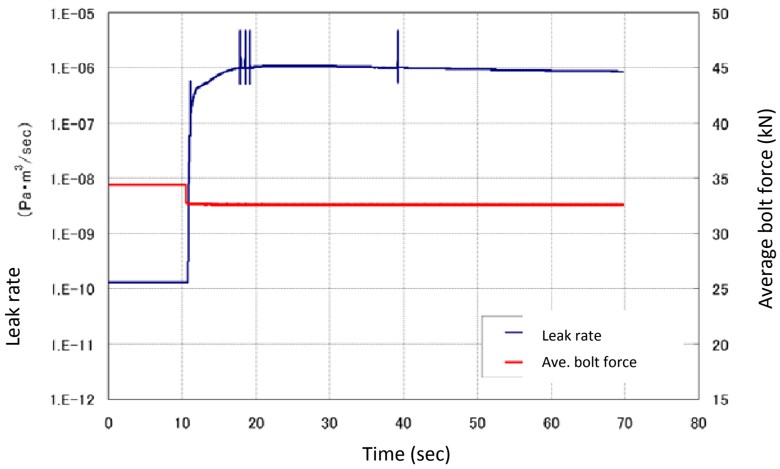


Figure 10-b. Leak rate and average bolt force as a function of time

ACKNOWLEDGEMENT

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