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Thermal Test using a Half Scale Model of Shipping Package

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1. Introduction

To safely transport the radioactive waste arising from nuclear power plant, a shipping package is required. Therefore, Korea Radioactive Waste Agency (KORAD) is developing a KORAD-B/II shipping package to transport the high-level radioactive waste arising in the nuclear power plant. The regulatory requirements for a shipping package are prescribed that a Type B package must be able to withstand a temperature of 800 °C for a period of 30 min [1]. Therefore, a thermal test was conducted using a one-three in the length of the KORAD-B/II shipping package in a furnace with chamber dimensions of 3 m (W) × 4 m (L) × 2 m (H).

The KORAD-B/II shipping package was designed as a shipping cask to transport C4 concrete package which is temporarily stored at the HANUL nuclear power plant. Its outer diameter is 1,592 mm and its overall height is 1,570 mm. It weighs approximately 14.6 t. It consists of a thick-walled cylindrical cask body, a lid, adaptor to hold the C4 concrete package, and impact limiters. The cask body is made of carbon steel with cladding. The lid is made of stainless steel and is fixed to the cask body using stud bolts and cap nuts. The shock absorber is made of stainless steel and the inner space is filled with spruce wood.

This paper discusses the experimental approach used to estimate the thermal integrity of the KORAD-B/II shipping package at a temperature of 800 °C.

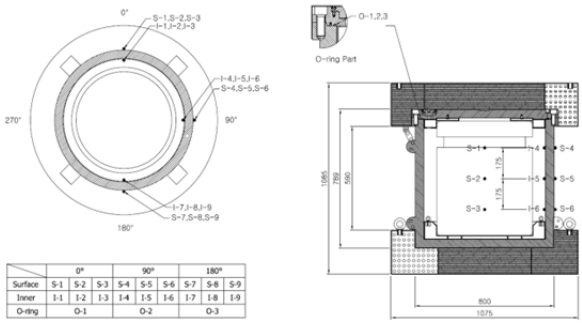
2. Thermal Test

2.1 Description of the Test Model

The test model is a half scale model of a real KORAD-B/II shipping package. Figure 1 shows the configuration of the thermal test model. The test model had an outer diameter of 800 mm and a length of 789 mm. The test model contained 21 thermocouples, which were located on the containment seal, as well as on the exterior and interior surfaces of the cask body.

2.2 Thermal Test

Before the thermal test, the half-scale model was damaged by both a 9 m drop test and a 1 m puncture test. Prior to the thermal test, the accelerometers and strain gages installed in the half scale model were removed. The shock absorber is made of stainless steel and the inner space is filled with spruce wood. As shown in Figure 2, the puncture area of the upper shock absorber ruptured by the puncture bar was filled with fireproof material to minimize combustion effect.



	0°			90°			180°		
Surface	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9
Inner	I-1	I-2	I-3	I-4	I-5	I-6	I-7	I-8	I-9
O-ring	O-1			O-2			O-3		

Fig. 1. Configuration of the thermal test model

Fig. 2. Half scale model installed in the furnace

The required duration for the thermal test was determined by comparing the half scale model heat input to the full scale cask regulatory specific heat input.

The fire duration for the half scale model was calculated as 1,273 seconds based on the following equation:

$$\tau_T = \frac{Q_p M_M}{\left(\pi D_M L_M + 2 \times \frac{\pi D_M^2}{4}\right) \sigma F T_F^4} \quad (1)$$

where, D_M is the scale model diameter, L_M is the test model length, T_F is the furnace temperature, M_M(1,800 kg) is the test model mass, and F is the view factor for a package in a furnace.

The thermal tests were carried out in a furnace with dimensions of 3.5 m(W) × 4.0 m(L) × 3.0 m(H). The thermal tests were performed as follows:

- The test model was installed in the center of the furnace.
- Twelve thermocouples were installed to measure the flame temperature inside the furnace.
- The furnace was heated at 800 ºC.
- The test model was maintained at an average temperature of at least 800 °C for 22 minutes.

Table 1. Average flame temperature during thermal test

Before Ignition	Growth	Steady State	Natural Cooling
	9 min	30 min	
27 °C	537 °C	816 °C	27 °C

- Upon completion of the thermal test, the test model was allowed to cool down naturally.

2.3 Test Results and Discussion

Table 1 lists the average flame temperature in the growth, steady-state, and cooling periods. The average flame temperature measured in the thermal test was 537 °C in the growth period and 816 °C in the steady-state period. Therefore, the thermal conditions prescribed in the regulatory guidelines were satisfied.

The most important items of concern for a thermal test are the peak temperature of the cask body and the seal temperature at the containment boundary. Table 2 lists the maximum temperatures measured during the thermal test using the half-scale model. Figure 3 shows the temperature history of the half-scale model in the thermal test.

The maximum surface temperature of the cask body was 434 °C in the upper part of the 90° direction. In the 0° direction, the maximum surface temperature of the cask body was 334 °C in the middle part. In the 180° direction, the maximum surface temperature of the cask body was 318 °C in the middle part. Soot was not formed on the surface of the cask body.

The maximum inner-surface temperature of the cask body was 406 °C in the upper part in the 90° direction. In the 0° and 180° directions, the maximum inner-surface temperature of the cask body was 324 and 308 °C, respectively, in the middle part.

The maximum temperatures of the containment seal in the 0°, 90°, and 180° directions, measured using the thermocouples installed in the lid to the depth of the seal, were (204, 281, and 207) °C, respectively. According to temperature range presented in the Parker O-ring Handbook, perfluoro-elastomer is normally recommended to be kept lower than 320 °C [2]. In the test, the maximum temperature of the containment seal was lower than the manufacturer's recommended maximum temperature.

The maximum temperatures of the cask body and the containment seal were lower than the permitted maximum temperature limits. Therefore, the thermal integrity of the KORAD-B/II shipping package was considered to have been maintained.

In the thermal test using the half-scale model, high temperatures were measured in the 90° direction. When the wood is heated, it produces pyrolysis products such as a char, tars, and gases. The remaining products of the pyrolysis of the wood are gases consisting of a mixture of hydrocarbons [3]. Therefore, it is likely due to the increased heat transfer from the flames produced by the combustion of gases generated by pyrolysis of the wood in the 90° direction.

Table 2. Thermal test results

		Surface	Inner-surface	O-ring
0°	Upper	307	298	204
	Middle	334	324	
	Lower	292	281	
90°	Upper	434	406	281
	Middle	423	400	
	Lower	345	327	
180°	Upper	302	292	207
	Middle	318	308	
	Lower	282	268	

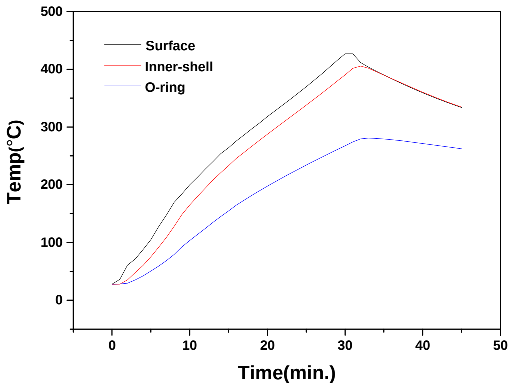


Fig. 3. Temperature history of the half scale mode

3. Conclusion

The thermal tests were conducted to estimate the thermal integrity of the KORAD-B/II shipping package at a temperature of 800 °C. The main results are described below.

Firstly, the maximum surface temperature of the cask body and the containment seal were lower than the permitted maximum temperature limits. Therefore, the thermal integrity of the KORAD-B/II shipping package could be estimated to maintain.

Secondly, the high temperatures were measured in the 90° direction due to the increased heat transfer from the flames produced by the combustion of gases generated by pyrolysis of the wood in the 90° direction.

REFERENCES

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[2] Parker Seal Company, Parker O-Ring Handbook, Catalog ORD 5700/US, pp. 18, 2007

[3] Quintiere. J.G. Fundamentals of Thermal Phenomena, John Wiley & Sons, New York, 2006.