INVESTIGATION OF AVAILABILITY OF RIGID POLYURETHANE FOAM AS SHOCK ABSORBING MATERIAL FOR HEAVY CASK

Jun OKADA
HITACHI ZOSEN CORPORATION

Satoshi ASHIDA
HITACHI ZOSEN CORPORATION

Akio OIWA
HITACHI ZOSEN CORPORATION

Hiroaki ARAI
HITACHI ZOSEN CORPORATION

Masayuki TANIGAWA
HITACHI ZOSEN CORPORATION

ABSTRACT

In this study rigid polyurethane foams (R-PUF) were chosen as a shock absorbing material and availability of the impact limiter using R-PUF was investigated by experiments. Results obtained by drop tests and fire resistant tests suggested that R-PUF worked well as a shock absorbing material, and would be useful for impact limiters of heavy casks.

INTRODUCTION

For the impact limiter of a transportation cask, wood has been mainly used as a shock absorbing material because it had enough capability with the limited volume. However, it has become difficult to procure wood in large quantities constantly with satisfying the characteristics specified in the design.

In this study, R-PUF was chosen as an alternative shock absorbing material and availability of the impact limiter using R-PUF was investigated by experiments.

Firstly, the shock absorbing performance of R-PUF with three different density types was investigated under different temperature conditions. Weight drop tests using column shaped test specimens were performed to obtain the shock absorbing property. Weight drop test used the heavy weight (about 300kg), which was freely dropped on the specimen from 3m in height.

Secondary, drop tests of 1/3 scale cask model with R-PUF impact limiters were carried out. Availability of R-PUF as shock absorbing materials was evaluated in comparison with the result of 1/3 scale drop test with impact limiter using plywood which was reported at PATRAM2004 [1].

Thirdly, the fire resistant performance of R-PUF was studied. In the test, cubic test specimens of R-PUF covered by stainless steel sheet were kept 800°C in the 800°C furnace for 30 minutes, and their fire resistant capability was verified.

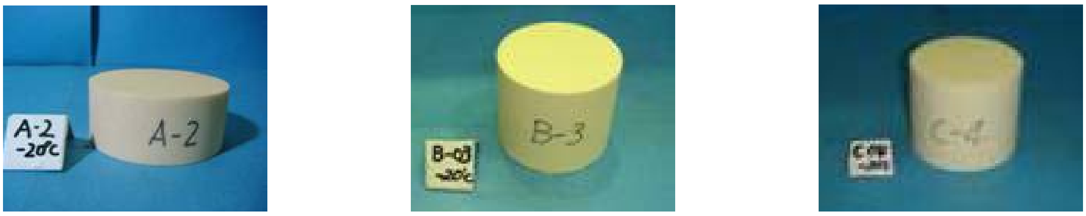
DROP WEIGHT TEST

Test method

To investigate the shock absorbing performance of various types of R-PUF under different temperature conditions, the column shaped test specimens were cut out as shown in Figure 1 and Table 1. Test specimen on the target plate was crushed by the weight (about 300kg) dropped from 3m in height (impact velocity is 7.7m/s) using the experimental apparatus as shown in Figure 2. In this study, 3 density types of test specimens were prepared as shown in Table 1. High density type (0.5g/cm^3) has almost the same density as the plywood reported at PATRAM2004 [1] and used in this experiment. In addition, to simulate the restraint condition of the actual impact limiter of the cask, side surface of the test specimen were constrained by R-PUF filler block and the steel tube, as shown in Figure 3. Temperature conditions in these experiments were settled in several grades from -40°C to 100°C, in which environments cask were possibly used. Under each temperature, relationship between stress and strain was investigated.

Measurement method

Displacement of the weight and the target plate were measured by non-contact displacement sensors at 4 points under the weight and 4 points under the target plate, respectively. Impact load was measured by the load cell under the target plate. They were measured with sampling frequency of 50kHz. Strain of the test specimen was defined by the ratio of the difference in the displacement between the weight and the target plate to the initial height of the test specimen. Stress of the test specimen was defined by the ratio of the impact load to the initial cross sectional area of the test specimen. Thus, the stress-strain curve of each test specimen was plotted.



(a) High density R-PUF (b) Middle density R-PUF (c) Low density R-PUF

Figure 1. Test specimen

Table 1. Test specimen of the drop weight test

Type of R-PUF	Density (g/cm^3)	Size Diameter (mm)	Size Height* (mm)	Mass (g)	Drop height of the weight (m)	Mass of the weight (kg)	Temperature conditions (℃)
High density type	0.52	79.9	35.5	91.4	3.00	305.5	-40, -20, 0, 25, 50, 75, 100
Middle density type	0.33	79.9	70.0	115.7	3.00	305.5	-40, -20, 0, 25, 50, 75, 100
Low density type	0.12	79.9	70.0	42.5	1.25	305.5	-40, -20, 0, 25, 50, 75, 100

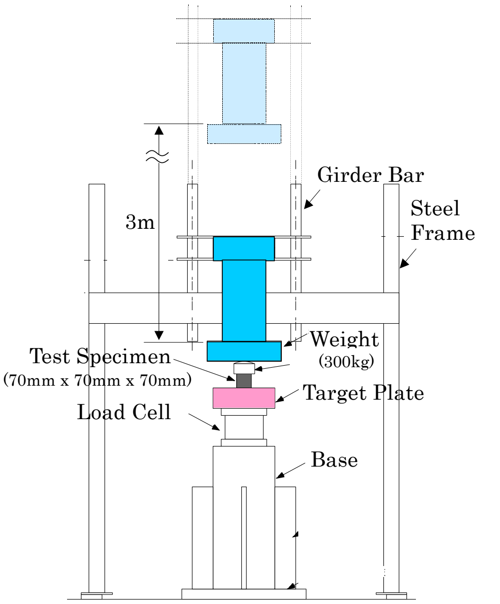


Figure 2. Experimental apparatus of drop weight test

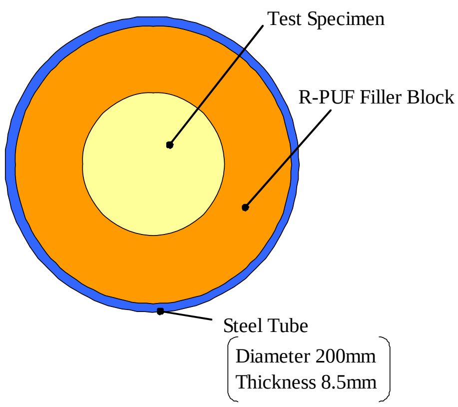
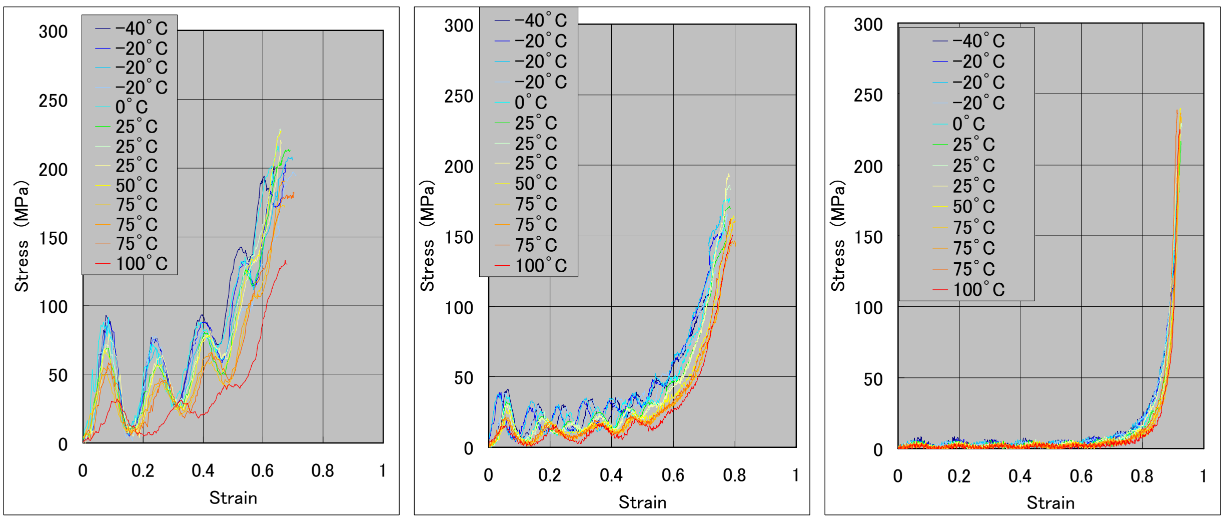


Figure 3. Restraint condition of test specimen

Test result of drop weight test

Stress strain curves of three density type of R-PUF under each temperature condition obtained by drop weight test are shown in Figure 4. All the three density types of R-PUF showed steep stress increase curves which indicated the loss of function as the shock absorbing material. Such steep stress increase was affected by the increase of temperature. Strain value where stress begins to increase steeply had a tendency to enlarge in association with the increase of temperature in three density types of R-PUF. As shown in this figure, high density R-PUF (a) is affected by extreme high temperature condition such as 100°C. On the other hand, middle and low density R-PUF (b, c), the temperature effect is few. Middle density type R-PUF(b) has almost the same shock absorbing capability as plywood, which has been reported in PATRAM2007 [2].



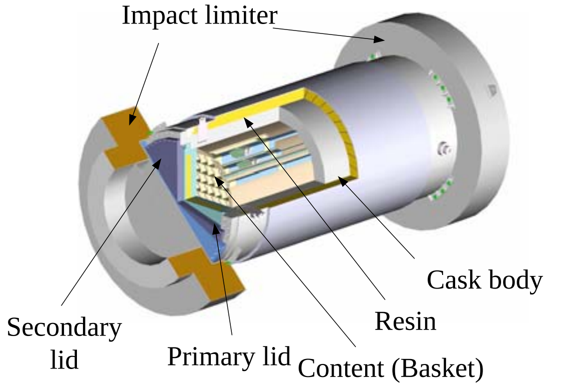
(a) High density R-PUF (b) Middle density R-PUF (c) Low density R-PUF

Figure 4. Stress-strain curves obtained by drop weight test

DROP TEST OF SCALE MODEL CASK

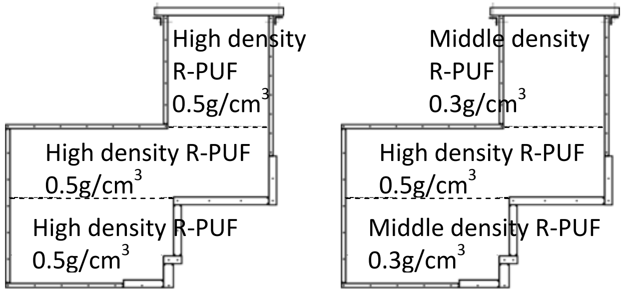
Test model of 1/3 scale cask

Figure 5 shows the Hitz-B69 cask (Transport and storage cask containing BWR 69 spent fuel) developed by HITACHI ZOSEN CORPORATION. In this study, to investigate the shock absorbing capability of R-PUF, side drop test with 1/3 scale model cask was carried out focusing on the impact limiter. The impact limiter consisted of R-PUF and steel cover plates that enclosed R-PUF. Diameters of the cask body and the impact limiter were 0.8m and 1.2m, respectively. Total length including impact limiters was 2.2m. Total mass was 4,950kg including the weight of impact limiters (440kg) and the content (dummy basket, 1210kg) of the cask. The weight of the model was approximately 1/27 of the actual cask. A pair of impact limiters was attached on the top and the bottom end of the cask with 12 bolts of M16 respectively.



(Length: 6.8m, Diameter: 3.5m, Mass: 132ton)

Figure 5. Hitz-B69 cask



(a) Type A (b) Type B

Figure 6. Impact limiter of 2 kinds of R-PUF

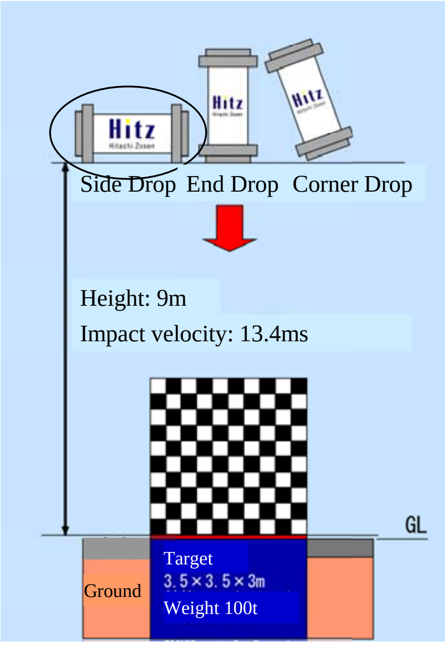


Figure 7. Overview of drop test of scale cask model

Test method and Measurement method

In this experiment, two types of impact limiter composed of different density of R-PUF were prepared. As shown in Figure 6 type A impact limiter was composed of high density R-PUF (0.5g/cm^3), which had the same density as plywood. Type B impact limiter was composed of both high and middle density R-PUF (0.3g/cm^3). The side drop tests of the cask with two types of impact limiters from 9m in height (impact velocity is 13.4m/s) were carried out according to IAEA regulation [3]. Figure 7 shows the overview of a drop test with 1/3 scale model cask. Acceleration of the cask was measured with sampling frequency of 50kHz at 6points, top and bottom of cask body, center of primary and secondary lids, and top and bottom of basket respectively. Measured data were processed with the low path filter of 400Hz.

Test result

Figure 8 shows the time history of impact acceleration of two types of R-PUF impact limiter and plywood impact limiter [1]. For example, focusing on the maximum acceleration of top of cask body, impact limiter of type A was 1670m/s^2, while that of type B was 1530m/s^2. This result indicates that type B impact limiter had better shock absorbing capability than type A impact limiter. Deformation of the scale model at the most destructive state is shown in Figure 9. Both lid-side and bottom-side impact limiters were damaged in each case. However, the cask body remained intact. Figure 10 summarized the maximum acceleration at measured 6 points. As shown in this figure, at all the six points, both impact limiter of type A and B showed better shock absorbing capability than plywood. Especially, type B R-PUF model showed 7-20% decrease in the maximum acceleration than plywood model at all the points measured, suggesting that impact limiter of type B had superior shock absorbing capability.

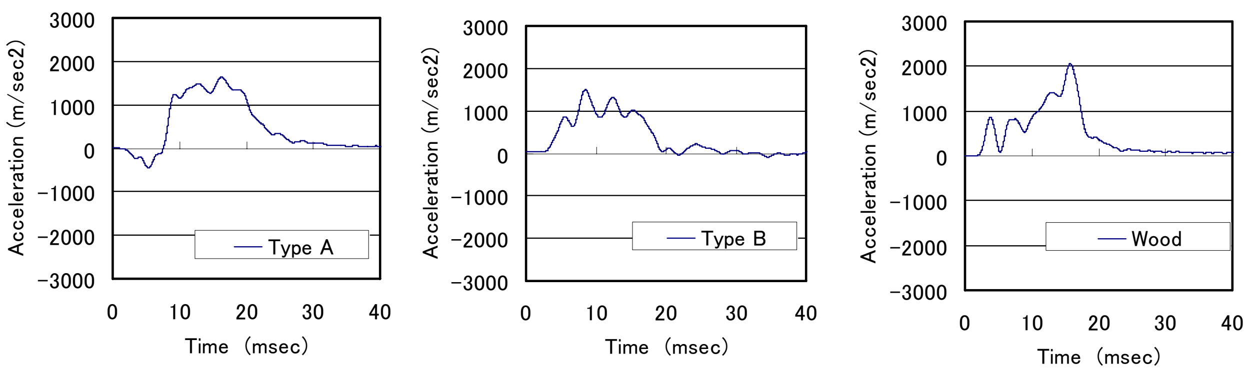
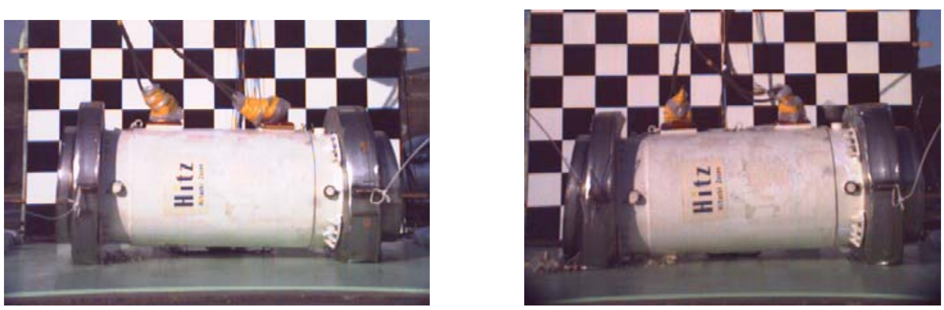


Figure 8. Time history of impact acceleration at the top of cask body



(a) type A (b) type B

Figure 9. Deformation of impact limiter at the most destructive state

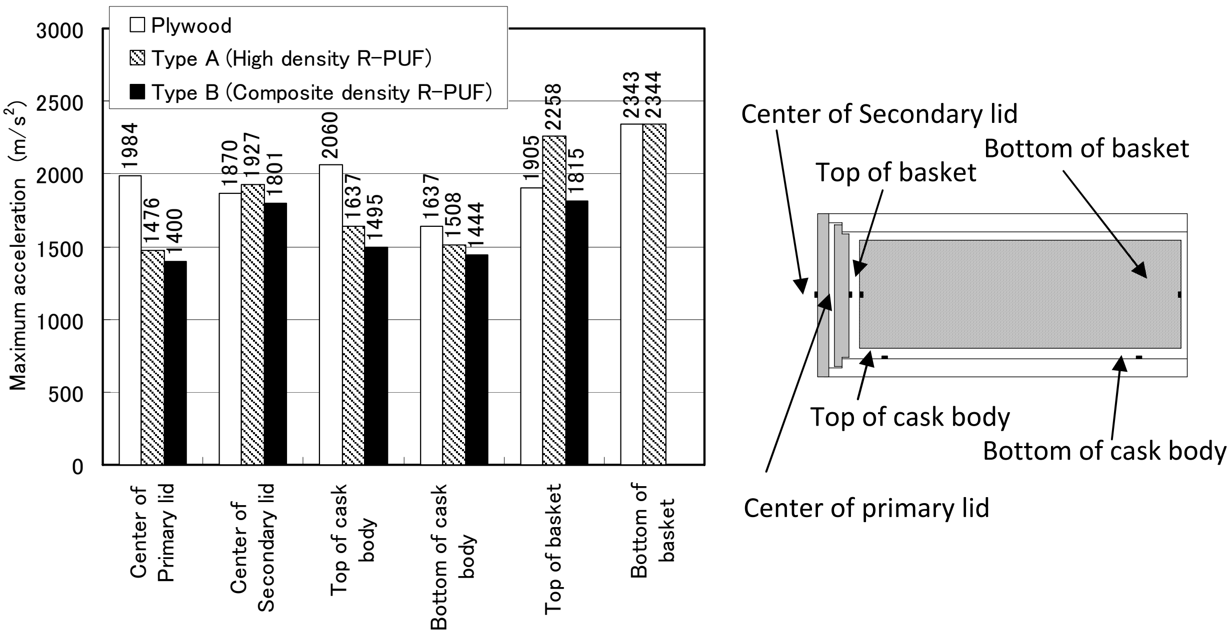


Figure 10. Maximum acceleration of measured 6 points

FIRE RESISTANT TEST OF R-PUF

Test method

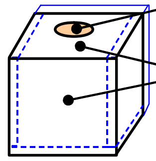
The fire resistant capability of R-PUF was examined by keeping the cubic test specimens in the 800°C furnace for 30 minutes according to IAEA [3]. The size of the furnace was 2m x 2m x 3m as shown in Figure 11. The test specimens were smoothly thrown into the furnace by rail, and inner temperature of the furnace was promptly returned to 800°C with heaters settled on four inside wall. After 30 minutes, the test specimens were taken out from the furnace by a carriage on the rail, and fire resistant capability of them was examined.

Details of the test specimens are summarized in Table 2. The test specimens of high density R-PUF, middle density R-PUF and plywood, sized 400 x 400 x 400mm were covered by stainless steel sheet. Two walls of the cube were heated and the rest of four walls were insulated, which simulated actual impact limiter of cask. Further, one of the heated walls had a hole of 150mm in diameter to simulate destruction of the impact limiter by fire accident. Heat sensor was set in 200mm depth of each test specimens, on the insulated surface of stainless steel sheet and inside of the furnace.

(a) Overview of furnace (b) Rail to furnace (c) Heater settled on 4 walls

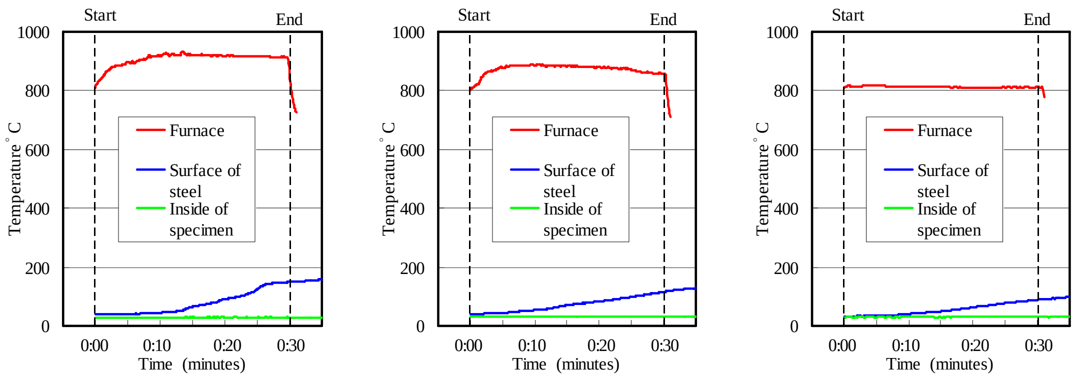
Figure 11. Furnace used in fire resistant test

Table 2. Test specimen of fire resistant test

Type of Test specimen	Density (g/cm^3)	Size of Test specimen	Thickness of cover plate	Structure of test specimen
High density R-PUF	0.52	400mm x 400mm x 400mm	Heated wall : 6mm Insulated wall : 3.2mm	
Middle density R-PUF	0.31			
Wood	0.54			

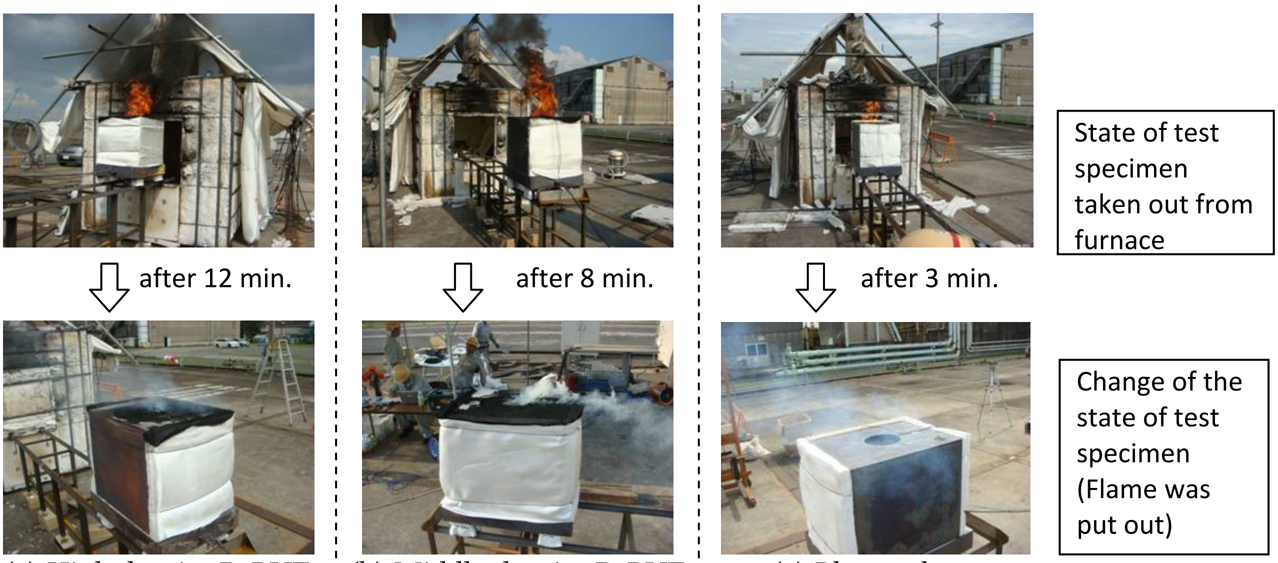
Test result

As shown in Figure 12, inner temperature of the furnace was kept more than 800°C during 30 minutes. Temperature of insulated surface of the stainless steel sheet showed a slight increase. In such condition, temperature of all the test specimens (high density R-PUF, middle density R-PUF and plywood) were kept in less than 40°C constantly, which suggested that all these test specimens did not transfer heat of inner temperature of the furnace.



(a) High density R-PUF (b) Middle density R-PUF (c) Plywood

Figure 12. Time history of temperature in fire resistant test



(a) High density R-PUF (b) Middle density R-PUF (c) Plywood

Figure 13. Overview of fire resistant test

After 30 minutes, test specimens covered by stainless steel sheet were taken out from the furnace, and then, were kept in the open air, and their fire resistant capability was examined. Just taken out from the furnace, surface of the specimens flamed from the settled hole on the top of stainless steel. As shown in Figure 13, flame of test specimen of plywood was put out after 3 minutes, while that of middle density R-PUF was put out after 8 minutes and high density RPUF after 12 minutes. Inside temperature of test specimen were monitored for about 24 hours after taken out from the furnace. During this time, temperatures did not increase more than 70°C. These results indicate that R-PUF showed almost the same fire resistant capability as plywood, and that actual cask body was not damaged by fire accident at the level of IAEA rule [3].

CONCLUSIONS

The conclusions obtained through this study are summarized as follows:

- Stress strain curves of three density type of R-PUF under each temperature condition were obtained by drop weight test.
- Results obtained by side drop tests of a 1/3 scale model cask suggested that the impact limiter composed of both high and middle density R-PUF had superior shock absorbing capability than that of plywood.
- Results obtained by fire resistant test suggested that R-PUF showed almost the same fire resistant capability as plywood and that actual cask body was not damaged by fire accident at the level of IAEA rule.

REFERENCES

[1] H. Tobita and K. Araki: Containment Performance of Transportable Storage Casks at 9m Drop Test. PATRAM2004, Berlin, Germany, 2004.

[2] J. Okada, S. Ashida, M. Tanigawa, A. Oiwa and H. Tobita: Investigation of Drop Impact Behavior of Cask Using Rigid Polyurethane Foams Shock Absorbing Materials. PATRAM2007, Miami, Florida, USA, 2007.

[3] IAEA: Safety Standards Series No.TS-R-1, REGULATION FOR THE SAFE TRANSPORT OF RADIOACTIVE MATERIAL, 2005 Edition.