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INVESTIGATION OF DROP IMPACT BEHAVIOUR OF CASK USING RIGID POLYURETHANE FOAMS AS SHOCK ABSORBING MATERIALS

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ABSTRACT

Drop impact behaviors of the cask using rigid polyurethane foams (R-PUF) as shock absorbing material were investigated by experiments and numerical simulations. To investigate the shock absorbing capability of R-PUF, side drop tests of a 1/10 scale cask model were carried out. Results obtained by side drop tests suggested that R-PUF worked well as shock absorbing materials, and would be useful for impact limiter of large transportation casks.

INTRODUCTION

The size of an impact limiter of a transportation cask is limited by operational condition. Therefore, wood has been mainly used as shock absorbing material because it has enough capability in the limited volume. However, it has become difficult to procure wood in large quantities constantly, which satisfies the characteristics specified by design. Additionally, some kind of wood is expensive. R-PUF was chosen as shock absorbing material for two reasons: firstly its characteristic of crush strength is adjustable, secondly R-PUF can be procured at low cost which is almost same as that of lowest-priced wood. There are few examples conventionally that adopted R-PUF as the impact limiter of large-scale transportation cask, but it is necessary to confirm whether R-PUF has enough performance to adopt it as shock absorbing material.

In this paper, drop impact behaviors of the cask using R-PUF as shock absorbing material were investigated both by experimental and analytical methods. Furthermore, reliability of the impact limiter using R-PUF was evaluated through comparison with the result of a 1/3 scale model drop test with plywood as shock absorbing material, which was reported at PATRAM2004 [1].

DROP WEIGHT TEST

Test method

To compare the shock absorbing performance of various types of R-PUF with plywood, the test specimens of the cube sized 70mm x 70mm x 70mm 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, 4 types of test specimens were prepared as shown in Table 1. For test specimens, two types of R-PUF produced by General Plastic Company (LAST-A-FORM FR3725, FR3730 [2]) were selected. FR3730 has almost same density as the plywood reported at PATRAM2004 [1] and used in this experiment. For plywood, two types of test specimens were used, in which crush directions were parallel and perpendicular to the layer. In addition, to simulate the restriction condition of the actual impact limiter of the cask, four-side surface of the test specimen were constrained by R-PUF filler block, wooden filler blocks, and the steel tube, as shown in Figure 3.

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)R-PUF(FR3725) (b)R-PUF(FR3730) (c)Plywood(parallel) (d) Plywood(perpendicular)

Figure 1. Test specimen of the drop weight test

Table 1. Test specimen

Material	Type	Size X (mm)	Size Y (mm)	Size Z* (mm)	Mass (g)	Density (g/cm^3)	Drop height of the weight (m)	Mass of the weight (kg)
R-PUF	FR3725	70.1	70.1	70.05	136.0	0.40	3.00	305.5
R-PUF	FR3730	70.1	70.0	70.1	168.6	0.49	3.00	305.5
Plywood	Parallel to the layer	70.1	70.1	70.1	181.1	0.53	2.50	305.5
Plywood	Perpendicular to the layer	70.1	70.0	70.0	179.5	0.52	3.00	305.5

*: Z indicates the direction of falling weight.

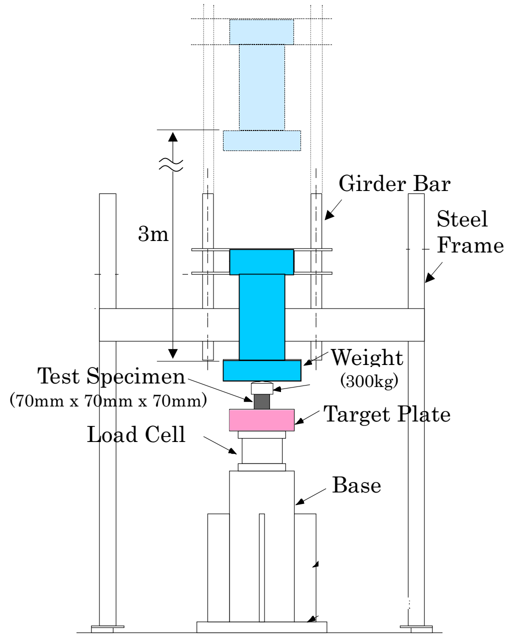


Figure 2. Experimental apparatus of drop weight test

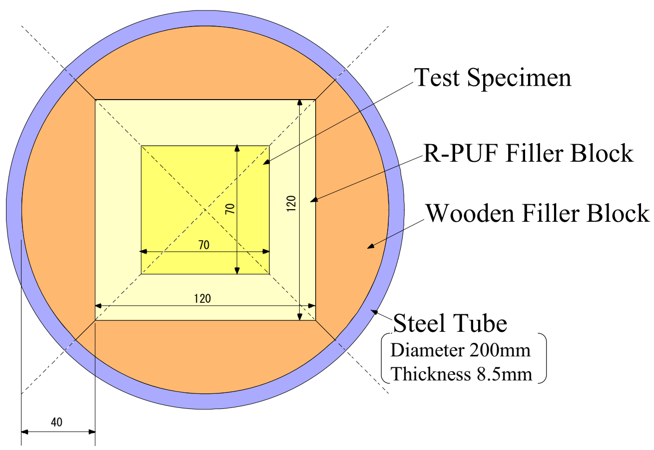


Figure 3. Restraint condition of test specimen

Test result of drop weight test

Stress strain curves of each material obtained by drop weight test are shown in Figure 4. As a result, plywood (perpendicular to the layer) was the lowest strength in all the test specimens. As shown in this figure, steep stress increase was observed at the strain value of 0.5, which indicated the loss of function as the shock absorbing material. The rest of 3 test specimens did not show such steep stress increase. On the other hand, R-PUF (FR3725) and the plywood (parallel to the layer) showed the approximately equal stress strain curve. In this experimental condition (Mass of the weight: 300kg, Drop height of the weight: 3m), R-PUF (FR3730) showed the best shock absorbing performance. Results of comparative drop weight test using R-PUF with the same density as plywood showed that R-PUF was superior to plywood in shock absorbing capability.

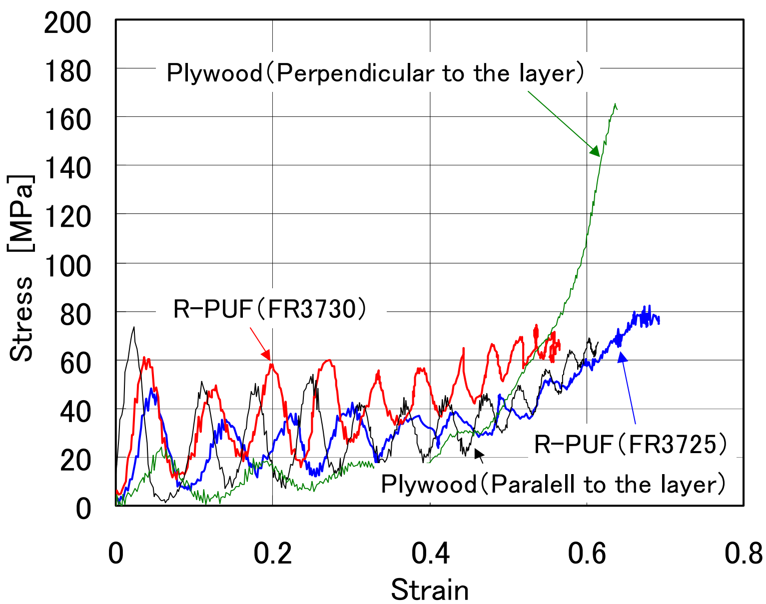
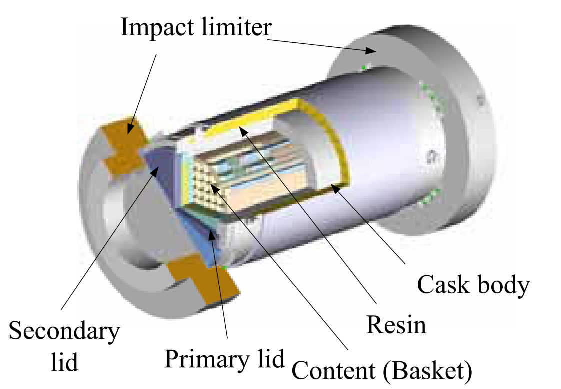


Figure 4. Stress-strain curves obtained by drop weight test

DROP TEST OF SCALE MODEL CASK

Test model of 1/10 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 1/10 scale model cask was carried out focusing on the impact limiter. The impact limiter consisted of R-PUF (Type: FR3730) and steel cover plates that enclosed R-PUF. 1/10 scale model test of Hitz-B69 cask is shown in Figure 6. Diameters of the cask body and the impact limiter were 0.27m and 0.36m, respectively. Total length including impact limiters was 0.61m. Total mass was 128kg including the weight of impact limiters (7kg) and the content (dummy basket, 32kg) of the cask. The weight of the model was approximately 1/1000 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 M6 respectively.



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

Figure 5. Hitz-B69 cask

Figure 6. 1/10scale cask model

Test method and Measurement method

The side drop test of the cask from 9m in height (impact velocity is 13.4m/s) was carried out according to IAEA regulation [3]. Figure 7 shows the overview of a drop test with 1/10 scale model cask. The target of the drop test was a reinforced concrete block (BWH 3.5mx3.5mx3.0m) with a 40mm thick steel-plate fixed on its top. The mass of the target was about 770 times of the drop object, which met the requirement of the IAEA regulation. Acceleration of center of cask body, center of lid and bottom of cask body were measured with sampling frequency of 50kHz.

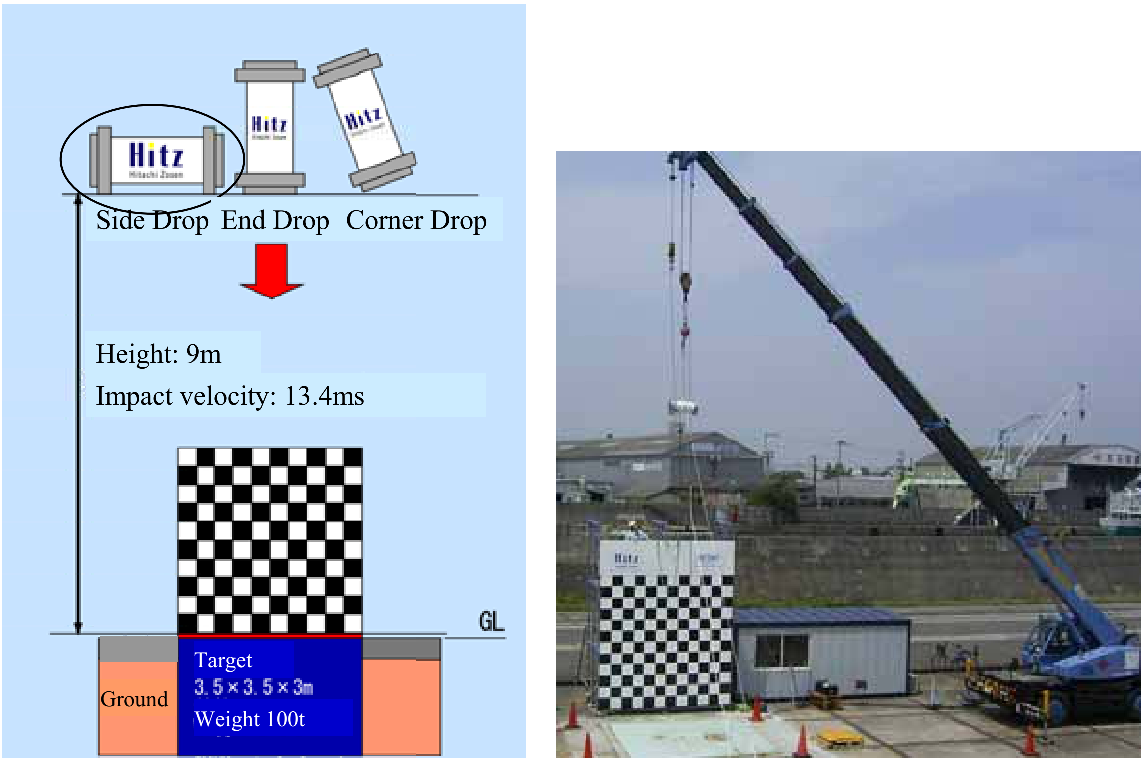


Figure 7. Overview of drop test of scale cask model

Test result

Figure 8 shows the time history of impact acceleration. Measured data were processed with the low path filter of 1000Hz. As shown in this figure, bottom-side dropped on the target about 1msec earlier than lid-side. The maximum acceleration at the center of lid was $5790 m/s^2$ (the bottom of cask body: $5484 m/s^2$). Deformation of the scale model after drop test is shown in Figure 9. Both lid-side and bottom-side impact limiters were damaged, however, the cask body remained intact. Thus, the impact limiter composed of R-PUF showed sufficient shock absorbing capability. Table2 summarized the maximum acceleration of lid and cask body obtained by this study in comparison with the result of 1/3 scale drop test using plywood as the shock absorbing material. The value of maximum acceleration was converted to the value of actual size according to the similarity law. In this table, the R-PUF model showed 2-7% lower than the plywood model in the maximum acceleration. Thus, the impact limiter composed of R-PUF indicated superior shock absorbing capability to that composed of plywood.

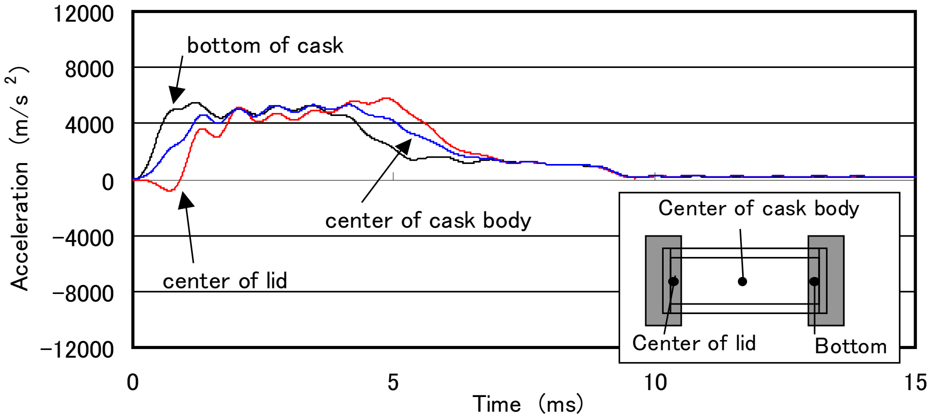


Figure 8. Time history of impact acceleration

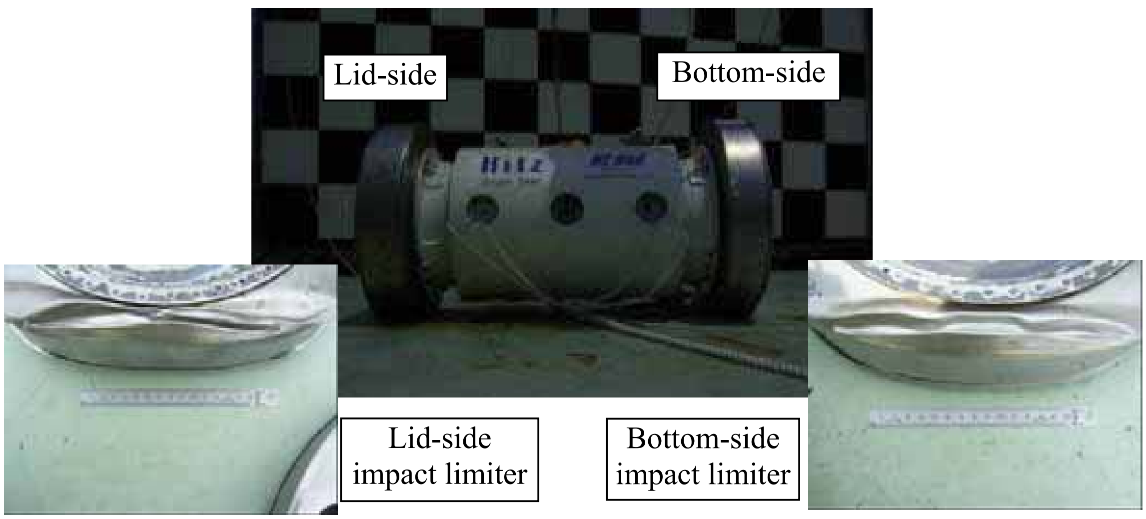


Figure 9. Deformation after drop test

Table 2. Maximum acceleration

Material of impact limiter	Scale	Drop orientation	Maximum acceleraion*	
			Lid (m/s^2)	Cask body (m/s^2)
R-PUF (FR3730)	1/10	Side Drop	579.0	532.1
Plywood**	1/3	Side Drop	623.3	545.6

*: Max acceleration was converted to the value of actual size cask according to the similarity law
**: Result of the plywood as material of the imapct limiter refers to [1]

NUMERICAL SIMULATION OF SCALE CASK MODEL

Numerical simulation model

A Finite Element (FE) code (LS-DYNA [4]) was used for the numerical simulation of 1/10 scale cask model, and the results were compared with the experimental results. A half part was modeled considering the symmetrical condition of geometry and load as shown in Figure 10.

Total of 42262-nodes and 35018-elements were used for the FE-model. The cask body, the lids, the R-PUF, and the dummy basket were modeled with 28728 solid elements. The outer casing, the resin cover, the impact limiter except for R-PUF were modeled with 6266 shell elements. And the impact limiter attachment bolts were modeled with 12 two-node beam elements.
Contact conditions were taken into consideration in the FE-model. A contact friction factor of 0.2 was applied for all contact surfaces as follows:

- Impact limiter <–> lids, cask body, brackets for impact limiter
- Cask body <–> dummy basket

Carbon steel used for the cask was modeled assumed as a linear strain-hardening material. Strain hardening coefficient was assumed 1/100 of the modulus of elasticity. As for the mechanical properties of the R-PUF, the stress-strain curve as shown in Figure 4 was used.

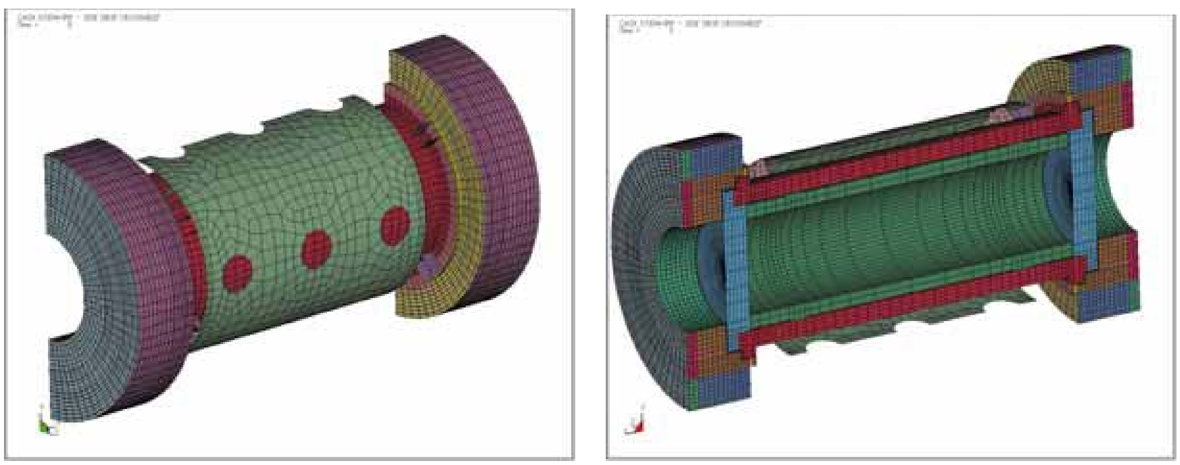


Figure 10. The FE model of 1/10 scale Hitz-B69 cask

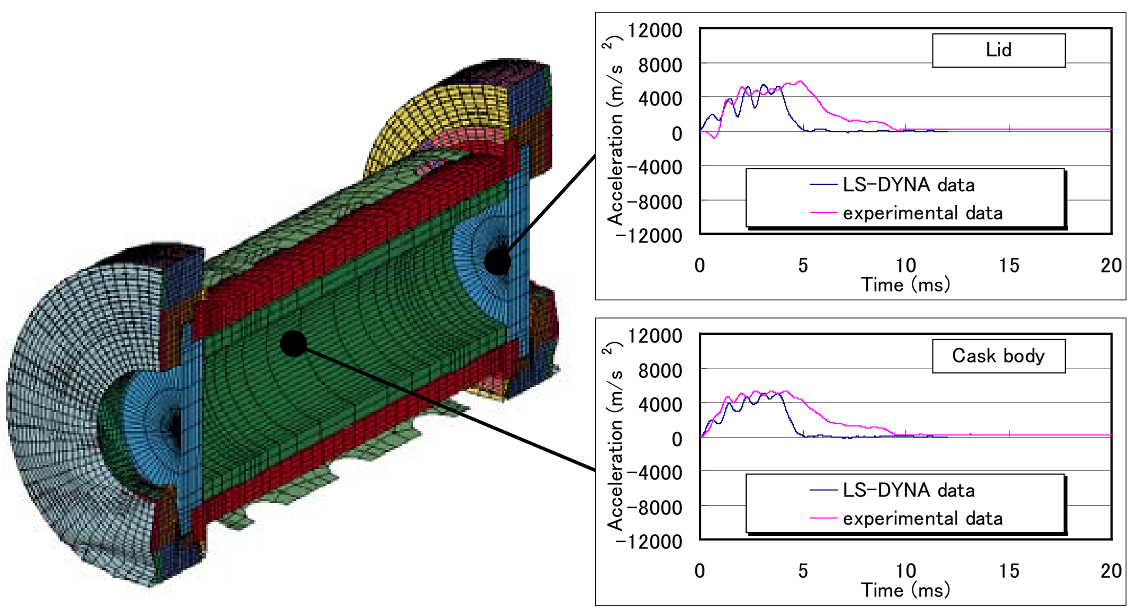


Figure 11. Numerical simulation result

Comparison of numerical simulation result to experimental result

Figure 11 shows the deformation of the impact limiter at the time when the maximum acceleration was calculated in LS-DYNA analysis. The time history of impact accelerations at the lid and the cask body were also compared between the numerical simulation and experimental results as shown in Figure 11. Both of these results were obtained under the condition of low path filter of 1000Hz. The time history of acceleration obtained by LS-DYNA analysis is similar to those of experimental results. Thus, LS-DYNA analysis was verified to be useful to predict the drop impact behavior of the cask.

CONCLUSIONS

The conclusions obtained through this study are summarized as follows:

- Results of drop weight test using R-PUF and plywood showed that R-PUF was superior to plywood with the same density in shock absorbing capability.
- Results obtained by side drop tests of a 1/10 scale model cask suggested that R-PUF worked well as shock absorbing materials, and is useful for impact limiter of large-scale transportation cask.
- Results obtained by LS-DYNA analysis show the similar tendency to the data obtained by the experiments. Thus, LS-DYNA analysis was confirmed to work well to predict the behavior of impact acceleration of the lid and the cask body.

In future, shapes of the R-PUF block and the proper placement of blocks in the cover of impact limiter will be investigated to design a good performance impact limiter with the reasonable cost. Furthermore, drop tests with 1/3 scale model cask are going to be done in order to verify the capability of it.

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