Proceedings of the 19th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2019
August 4-9, 2019, New Orleans, LA, USA

Applicability of Rigid Polyurethane Foam to Laying Type Shock Absorber

Akira TAO
Hitachi Zosen Corporation

Hiroyuki MORITA
Hitachi Zosen Corporation

Abstract

We successfully applied the Rigid Polyurethane Foam (R-PUF) to shock absorber for a transportation cask. In case of drop event at nuclear facility from the height of 40 meters or more, the experiences of that development of shock absorber for a transportation cask will be applied to laying type shock absorber that is located under the lifted cask in order to mitigate an impact force. An abundant data regarding the drop impact test has been obtained by dropping the shock absorber for transportation cask in a free fall state and knowledge from them[1], but it is necessary to get performance data with regard to design and experiment for laying type shock absorber. In order to design laying type shock absorber, we try to apply the method of the Uniaxial Displacement Method (UDM), which is used in CRUSH code : a simplified computer program for impact analysis of radioactive material transport casks, to evaluate the impact acceleration of the cask body and the deformation of the shock absorber that is in free drop event.

In this study, static compression tests and falling weight impact tests are conducted by using some weights that have respectively different tip shapes to simulate various postures of the freely falling casks. This study definitely demonstrates the followings.

(a) Comparison between the experiment results and the prediction values based on UDM shows that the analysis method by UDM can be used to design considering an effect caused by the tip shape.

(b) It is possible to design the shock absorber considered by its density and an impact speed of the object regarding an influence by a shear failure of a material of shock absorber that an object went through.

Introduction

Wood is applied as a shock absorbing material for a shock absorber of a transportation cask in most designs. However, it is considered that wood has some problems of material management, such as insufficient species of wood suitable for the cask impact limiter, or cost for controlling moisture content. Therefore, R-PUF is expected to be an alternative material to improve constant availability and to easily manage costs and quality[2,3]. Regarding R-PUF as a shock absorbing material in impact limiter of transportation cask, we evaluate the impact acceleration of a cask and the deformation of the shock absorber that is in free drop event by using CRUSH code based on UDM; this method will be used for the evaluation under the assumption that the deformable region in the shock absorber consists of an assembly of many one-dimensional bar elements[4,5].

We had chosen R-PUF as an alternative material to wood, because its characteristic of crush strength is adjustable and R-PUF can be prepared at almost the same cost as low-priced wood. The cask shock absorber is not only attached to a cask, but also be located under a lifted cask without an impact limiter on site in order to mitigate an impact force in case of drop event. In some nuclear facilities, It is possible to lift a cask from the height of 40 meters or more, the shock absorber which have an extremely high cushioning performance is required. If a shock absorber attached to cask is dropped, the shock absorber deforms from the grounding surface because it is constrained by a cover plate. However, with regard to the laying type shock absorber made from R-PUF, the different behaviors ; piercing cushioning material by falling objects, splitting of the shock absorbing material under an influence by the tip shape of falling object, etc., would occur since it receives the dropped container on the grounding surface.

In this paper, the applicability of UDM into the laying type shock absorber is verified from the crushing characteristics data of static compression tests and falling weight impact tests.

Static Compression Tests

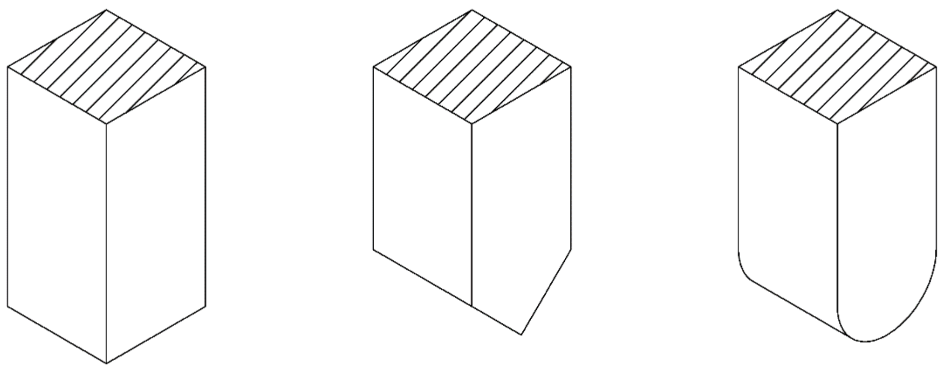
Three types of specimens are used; the single layer material of R-PUF (0.1 g/cm^3 and 0.3 g/cm^3), and the laminated R-PUF material (0.1 g/cm^3 + 0.3 g/cm^3). These specimens are loaded at constant static speed using the calibrated hydraulic uniaxial tester and various types of pushing bar until the specimen deforms up to 75 % strain.

Falling Weight Impact Tests

The specifications of specimens and pushing bars are same as that of static compression tests. A weight is dropped from the height exceeding the actual strain-rate ($9.34\ \mathrm{sec}^{-1}$). The mass of weight is set based on the previous test results, and the specimen deforms to about 70 % strain.

Pushing Bars

In order to simulate the drop posture of a cask onto the laying type shock absorber, three pushing bars having different tip shapes are used.



Type A Type B Type C

Figure 1. The tip shape of pushing bar

Specifications of specimen

Material : R-PUF

Dimensions : L 78 mm × W 58 mm × H 60 mm

Density : 0.1 g/cm^3 or 0.3 g/cm^3 (single layer specimen)

0.1 g/cm^3 + 0.3 g/cm^3 (laminated specimen)

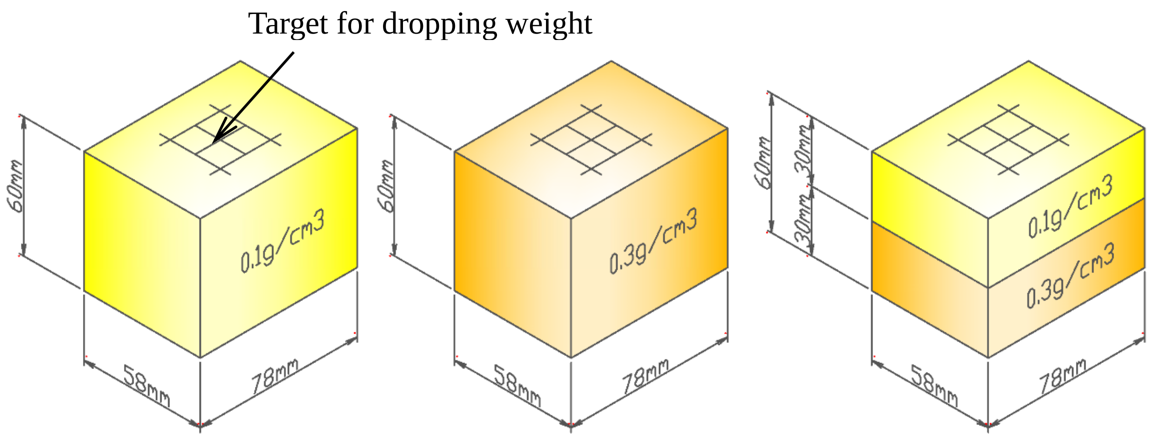


Figure 2. Three types of specimen

Test Conditions

Item of measurement : continuous measurement of displacement and load

Test temperature : room temperature

Table 1. Test conditions for static compression test

Case No.	Tip shape type	Specimen Density [g/cm^3]	Test conditions		Number of tests
			Strain-rate [sec^{-1}]	Maximum displacement [mm]	
1	A				3
2	B	0.1			3
3	C				3
4	A				3
5	B	0.3	1.67×10^{-3}	45	3
6	C				3
7	A				3
8	B	0.1+0.3			3
9	C				3

Table 2. Test conditions for falling weight impact test

<table>
<tr><th rowspan="2">Case No.</th><th rowspan="2">Tip shape type</th><th rowspan="2">Specimen Density [g/cm^3]</th><th colspan="3">Test conditions</th><th rowspan="2">Number of tests</th></tr>
<tr><th>Strain-rate [sec^{-1}]</th><th>Drop height [mm]</th><th>Weight [kg]</th></tr>
<tr><td>10</td><td>A</td><td rowspan="3">0.1</td><td rowspan="3">46.5</td><td rowspan="3">400</td><td rowspan="3">16.27</td><td>3</td></tr>
<tr><td>11</td><td>B</td><td>3</td></tr>
<tr><td>12</td><td>C</td><td>3</td></tr>
<tr><td>13</td><td>A</td><td rowspan="3">0.3</td><td>57.0</td><td>600</td><td>77.08</td><td>3</td></tr>
<tr><td>14</td><td>B</td><td>57.0</td><td>600</td><td>77.08</td><td>3</td></tr>
<tr><td>15</td><td>C</td><td>57.0
52.0
31.2</td><td>600
500
180</td><td>77.08</td><td>1
1
2</td></tr>
<tr><td>16</td><td>A</td><td rowspan="3">0.1+0.3</td><td rowspan="3">56.9</td><td rowspan="3">600</td><td rowspan="3">28.27</td><td>3</td></tr>
<tr><td>17</td><td>B</td><td>3</td></tr>
<tr><td>18</td><td>C</td><td>3</td></tr>
</table>

Predicted value by UDM

In order to compare the result of each test and the predicted value by UDM, we calculate a crushing characteristics using UDM based on the experimental conditions. The result shows that it is necessary to consider the effect of shear fracture against R-PUF pierced by dropping object. Considering our previous compression test data, the effect of the piercing shear fracture is estimated to be inversely proportional to the dimensional ratio. The following equation is used to consider the shear effect.

$$k = k_0 \times \frac{D_0}{D} \times \frac{\rho_{0.3}}{\rho}$$

k : Influence coefficient of piercing shear in the experiment [%]

k_0 : Estimated coefficient of piercing shear in an actual system ※1)

D : Base dimension in the experiment

D_0 : Base dimension in an actual system

ρ : Density of the shock absorbing material [g/cm^3] ※2)

$\rho_{0.3}$: Base Density（0.3[g/cm^3]） ※2)

※1 : The value has been calculated from our previous compression test data. This coefficient is used to evaluate the cushioning performance of the shock absorbing material pierced by a dropping object in an actual system.

※2 : We assume the density ratio coefficient based on density 0.3 g/cm^3 because the piercing shear influence coefficient is relevant to the density dependence in this experiment.

Thus, k=143 % in case that the density is 0.1 g/cm^3, and k=48 % in case that the density is 0.3 g/cm^3. We compare the predicted value by UDM corrected by the piercing shear influence coefficient and the crushing characteristic data obtained by the experiment.

Test Results

The results of static compression test

The results clarified good agreement with both predicted values and experimental results. Figure 3 ~ Figure 5 shows examples of the comparison of crushing characteristics data of each condition.

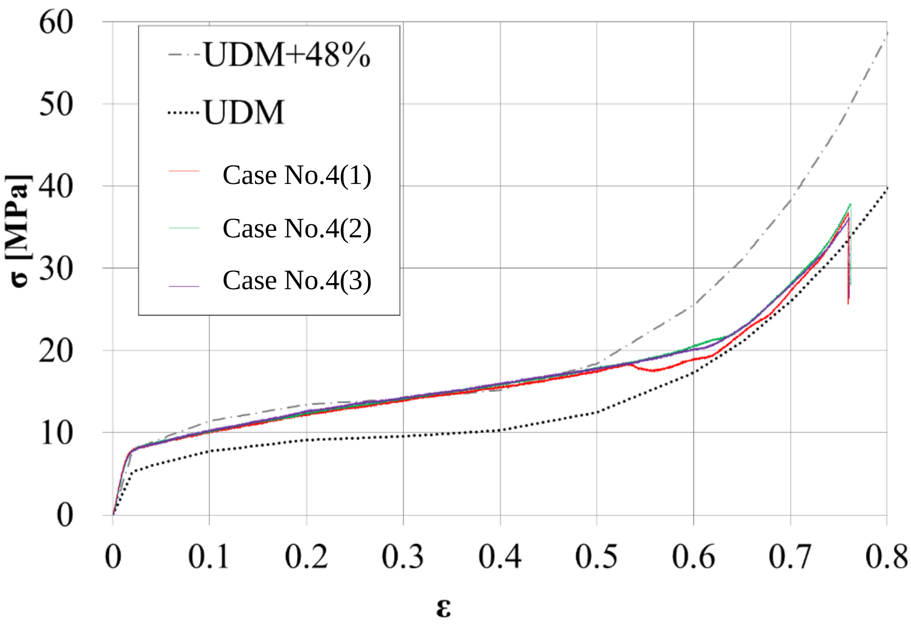


Figure 3. Comparison data of single layer specimen (Type A, 0.3 g/cm^3)

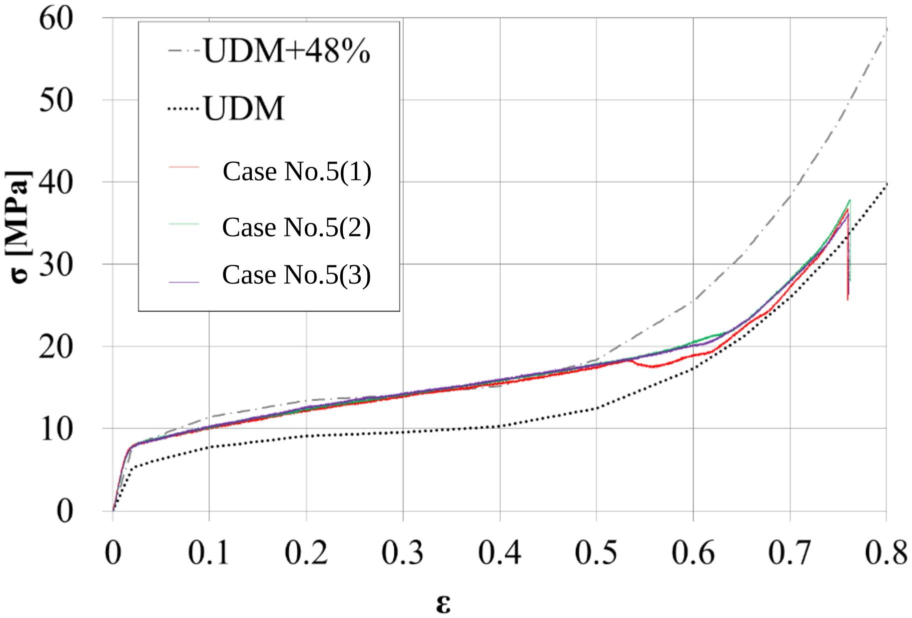


Figure 4. Comparison data of single layer specimen (Type B, 0.3 g/cm^3)

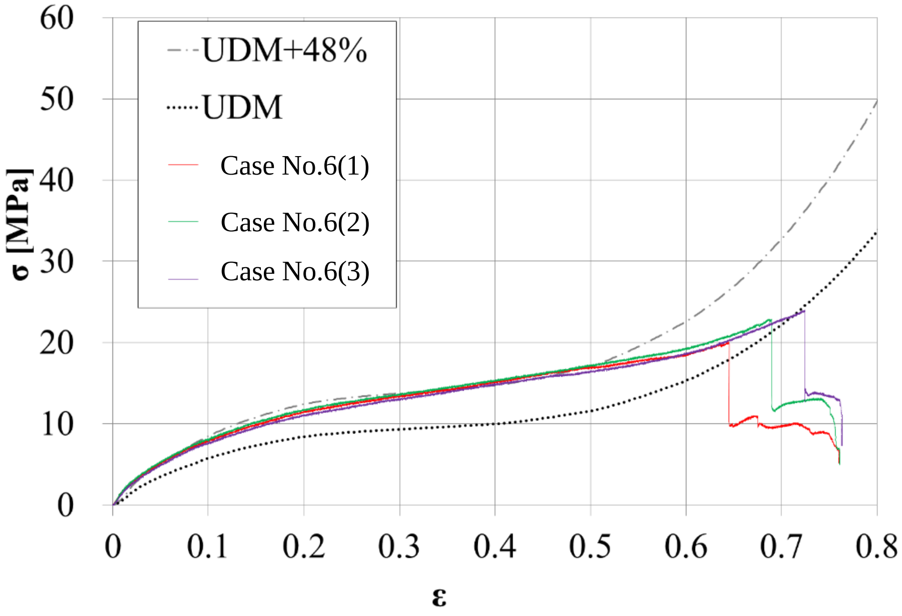


Figure 5. Comparison data of single layer specimen (Type C, 0.3 g/cm^3)

The results of falling weight impact test

The results clarified good agreement with both predicted values and experimental results. Figure 6 ~ Figure 8 shows examples of the comparison of crushing characteristics data of each condition.

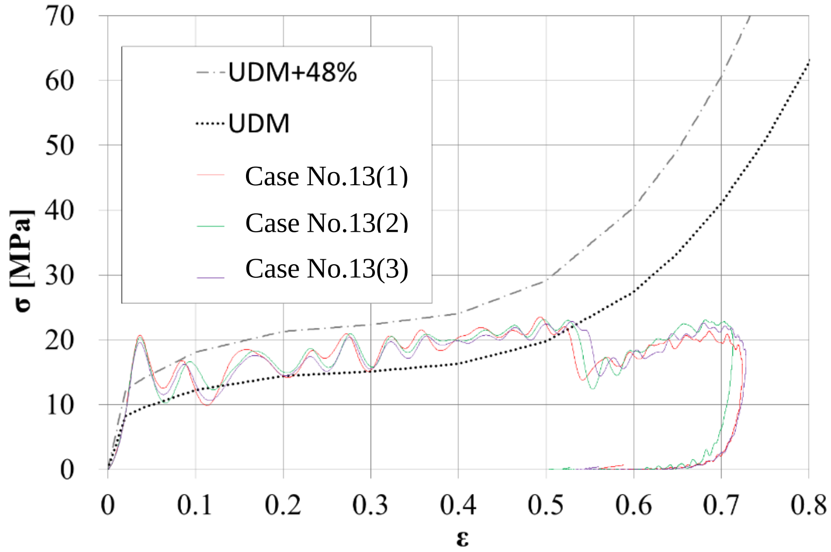


Figure 6. Comparison data of single layer specimen (Type A, 0.3 g/cm^3)

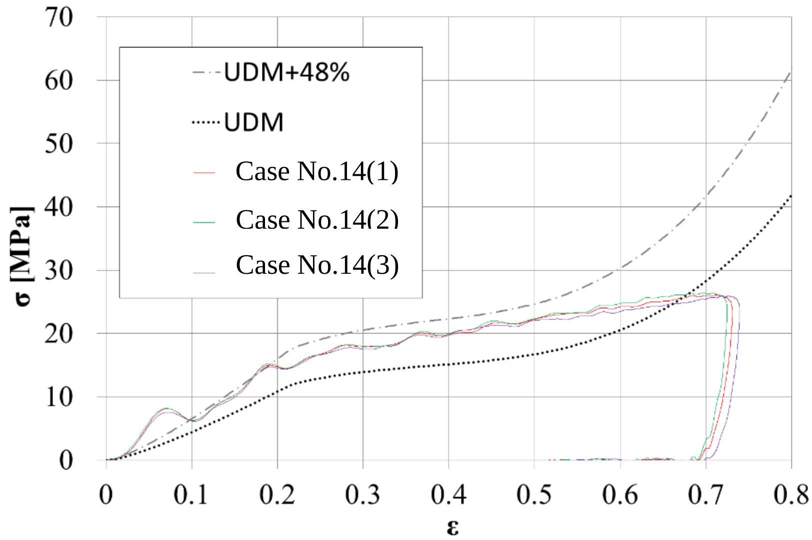


Figure 7. Comparison data of single layer specimen (Type B, 0.3 g/cm^3)

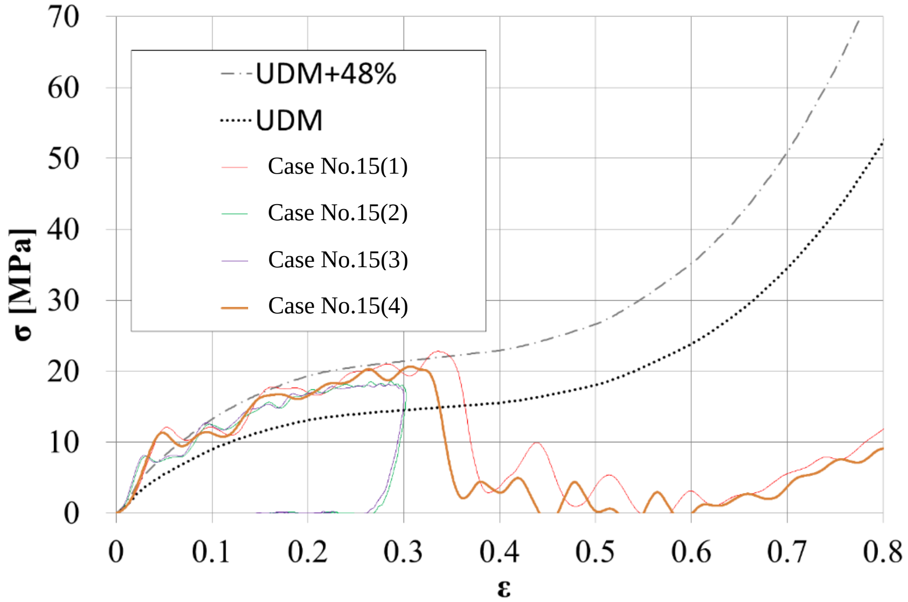


Figure 8. Comparison data of single layer specimen (Type C, 0.3 g/cm^3)

Discussion

These results show that the next four items are important to consider the UDM applicability.

(1) Effect of tip shape

The comparison of the experiment results and the predicted value by UDM considering the piercing shear effect shows that the predicted value by UDM is well matched the experimental result. It means the influence of tip shape for crushing characteristics can be evaluated by UDM. The effect of the tip shape has a special feature in crushing characteristics within 0.3 strain, and these characteristics can be predicted by UDM.

(2) Shear failure caused by piercing of a falling object

The effect of the piercing shear fracture is estimated to be inversely proportional to the dimensional ratio, and the predicted value of UDM matches the test result well by using the influence coefficient of piercing shear calculated from the size ratio between the test system and the actual system. As the results of the falling weight impact test tend to be closer to the predicted value by UDM which does not consider the piercing shear effect than the result of the static compression test, and the piercing shear effect is considered to be affected by the collision velocity. This tendency suggests the collision velocity is the higher, the influence is the smaller, and collision velocity is the smaller, the influence is the bigger.

(3) Splitting and cracking by collision tip shape

In the vertical cross-sectional observation of the specimen after the static compression test, the compressive force is spread as frustum shape from the loading surface, and the case that has occurred boundary shear cracks in boundary surface of the frustum shape be confirmed.

However, the effect by the shear cracks against the crushing characteristics is slight.

In the vertical cross-sectional observation of the specimen after the falling weight impact test, crashing by the shear cracks penetrating to side of the specimen is not caused. This result shows that the collision speed is the faster, the angle of the frustum shape by the compressive force is smaller.

Conclusions

This study definitely demonstrates the followings.

(a) Comparison between the experiment results and the prediction values based on UDM shows that the analysis method by UDM can be used to design considering an effect caused by the tip shape.

(b) It is possible to design the shock absorber considered by its density and an impact speed of the object regarding an influence by a shear failure of a material of shock absorber that an object went through.

References

[1] K. Namba, et al., “Applicability of Shock Absorber using a New Material for Radioactive Materials Transport Cask by Drop Tests”, CRIEPI Report No.N12020, 2013.5. (in Japanese)

[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] J. Okada, S. Ashida, A. Oiwa, H. Arai, and M. Tanigawa, “INVESTICATION OF AVAILABILITY OF RIGID POLYURETHANE FOAM AS SHOCK ABSORBING MATERIAL FOR HEAVY CASK”, PATRAM2010, London, UK, 2010.

[4] T. IKUSHIMA, et al., “Development of Simplifier Computer Codes for Impact Analysis of Radioactive Materials Transport Casks, (I) Computer Code CRUSH for Impact Analysis of Casks with Shock Absorbers”, Journal of the Atomic Energy Society of Japan 33(4), 381-390, 1991.

[5] T. IKUSHIMA, “Handbook for structural analysis of radioactive substance transportation container ”, the Japan Atomic Energy Research Institute, 1991. (in Japanese)