Shock absorbing evaluation of the rigid polyurethane foam and Styrofoam applied to a small transportation package

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ABSTRACT

The package design objectives for the drop condition are to maintain the integrity of the structural material by reducing the impact force. There are two kinds of the shock absorbing materials such as rigid polyurethane foam (PU) and Styrofoam (EPS: Expanded Poly Styrene). These materials are generally used in small transportation packages. The stress-strain curves were obtained by the compression tests until the PU and EPS reached their lock-up strain. This paper describes that, in the case of a small transportation package of a cylindrical shape, the shock absorbing effects were evaluated by utilizing the compression properties of the PU and EPS foam.

INTRODUCTION

Low and intermediate radioactive material transportation packages are used for the solid waste form in a nuclear power plant and also for the radioisotopes for industrial and medical applications. These transportation packages are relatively smaller than the spent fuel transportation packages. In the case of these small packages, the shielding materials and containment boundary are surrounded completely by a shock absorber. The structural integrity of the transportation packages should be sustained under the drop damage of a normal and hypothetical condition. [1] In order to lessen the force at the drop impact moment, it is important to select the correct shock absorbing materials and decide on the size of the shock absorber according to the package weight. The shock absorbing materials of small packages are generally PU foam and EPS foam.

The structural integrity of a drop impact is evaluated by the FEM computer code. And then, it is important that the correct material model of the shock absorber is applied in the FEM analysis. If the metallic skin of the shock absorber is not modelled in the drop analysis, the elastic-plastic material model provides a better match with the experimental data than the crushable foam model.[2] The young modulus, yield stress, plastic stress and strain are needed to perform the elastic-plastic analysis. These input data for the FEM analysis can be obtained through the compression test.

COMPRESSION TESTS OF POLYURETHANE FOAM AND STYROFOAM

The compression stress-strain data is used for the drop impact analysis of transportation packages. Compression tests were preformed by the universal tester, as shown in Fig. 1. This testing machine is capable of compressing a maximum of 2.5 tons. Test method referred to the standard of ASTM D 1621-00.[3] But, the size of the test specimen could not be satisfied with this standard because of the compression limit of the testing machine, the test specimens had a square cross section with 9 cm^2. The specimen size was 3 W x 3 L x 3 H cm. 17 kinds of test specimens are compressed, as shown in Fig. 2. 7 kinds of PU foams have a range of density between 58.85 and 525.43 kg/m^3. These PU foams are generally used for the thermal insulation of a building construction. And, 10 kinds of EPS foam have a range of density between 24.58 and 65.18 kg/m^3. These EPS foams are generally used for the shock absorbing materials of an electronic product package and a helmet.

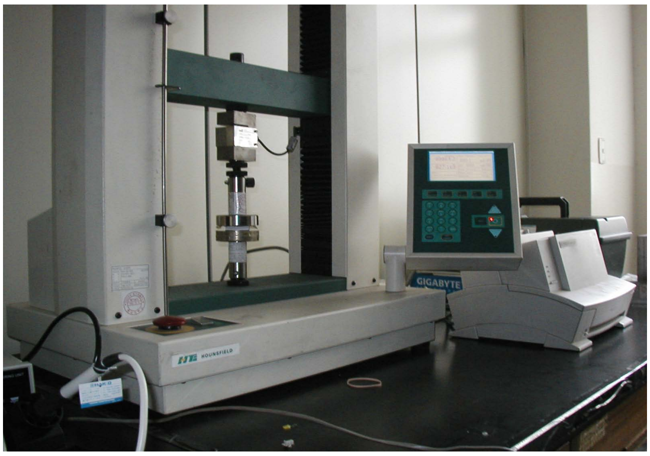

Fig. 1. Compression Tester (Hounsfield, H25K-ST)

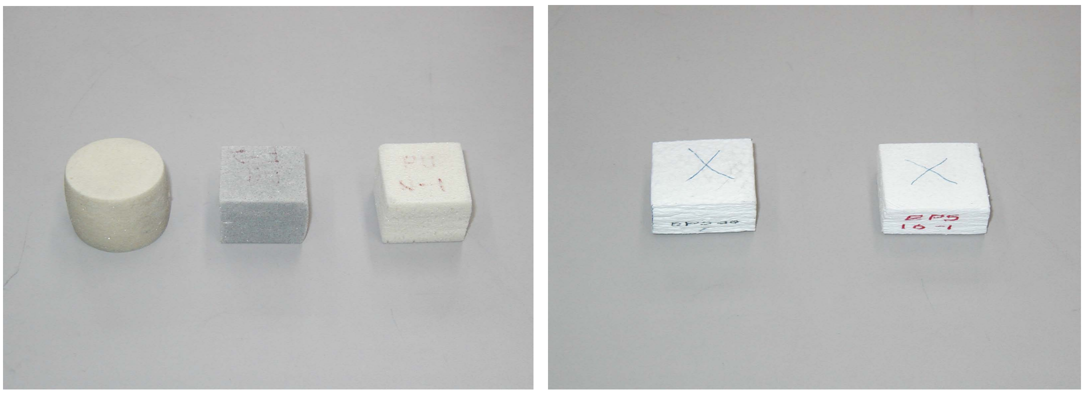

Fig. 2. Specimen of Polyurethane Foam and Styrofoam

COMPRESSION TEST RESULTS

To provide the computer analysis data such as the elastic modulus, yield stress, plastic stress and strain, the compression tests were performed. Force-deflection curves were at first obtained by the compression tester. Secondly, these force-deflection curves were converted to engineering stress-strain (e-S) data. Thirdly, the true stress-strain data was calculated in order to apply the elastic-plastic analysis to the drop impact. True strain and stress are generally ln(1+e) and S(1+e). By this calculation, the true strain was decreased and the true stress was increased when compared with the engineering stress and strain. Figs 3 - 6 show the true stress–strain of the polyurethane foam and Styrofoam according to the various densities. The young modulus, yield stress, plastic stress and strain were determined from these curves. The analysis input data was provided by using 4 -5 points extracted from these curves.

The PU foams and Styrofoam were classified into hard and soft materials according to the densities. The densities of hard PU foams were measured as 466 – 525 kg/m^3. These young modulus and yield stresses were estimated as 141 - 272 MPa and 1.45 – 5.30, as shown in Fig. 3. The specimens of the hard PU foam could not be compressed up to the strain of the lock-up, because the broken phenomena of the specimen occurred. The densities of soft PU foams were measured as 58.85 – 70.26 kg/m^3. These young modulus and yield stresses were estimated as 5.36 – 10.31 MPa and 0.21 – 0.41 MPa, as shown in Fig. 4. The strain of the lock-up occurred at about 55 %. The densities of hard EPS foams were measured as 40.55 – 65.18 kg/m^3. These young modulus and yield stresses were estimated as 8.15 – 19.22 MPa and 0.19 – 0.62 MPa, as shown in Fig. 5. The densities of the soft EPS foams were measured as the 58.85 – 70.26 kg/m^3. These young modulus and yield stresses were estimated as 3.71 – 5.37 MPa and 0.13 – 0.17 MPa, as shown in Fig. 6. The strain of the lock-up also occurred at about 55 %.

It was difficult to decide on the young modulus because the initial stresses are not increased proportionally to the strain. If the soft polyurethane foam is compared with the hard Styrofoam, these young modulus and yield stresses are a little different from each other.

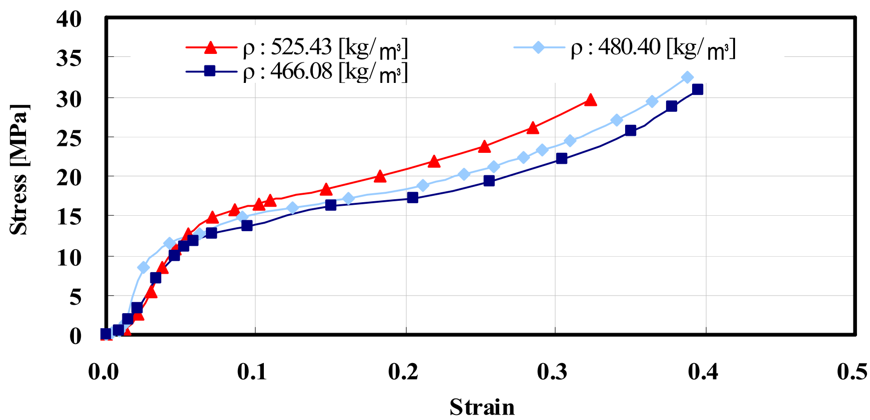

Fig. 3. Compression Stress-Strain Curve of Hard Polyurethane Foam

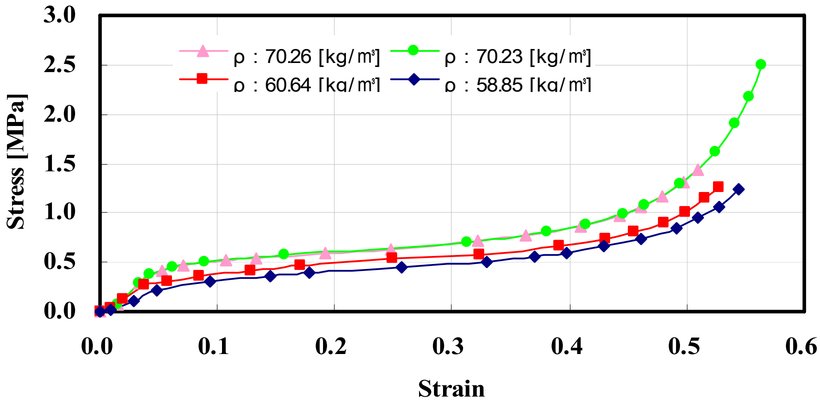

Fig. 4. Compression Stress-Strain Curve of Soft Polyurethane Foam

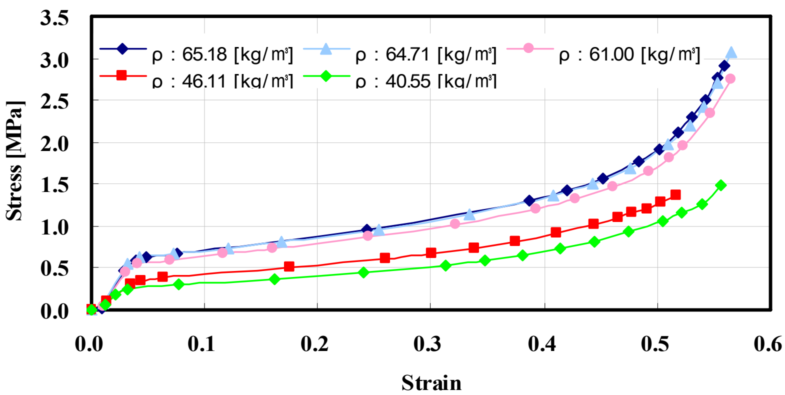

Fig. 5. Compression Stress-Strain Curve of Hard Styrofoam

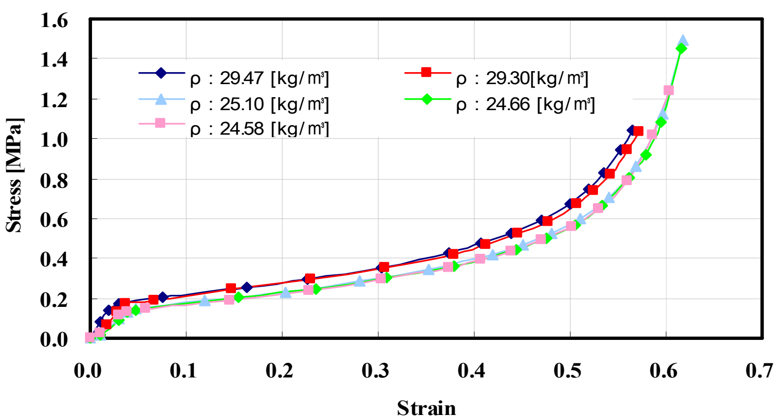

Fig. 6. Compression Stress-Strain Curve of Soft Styrofoam

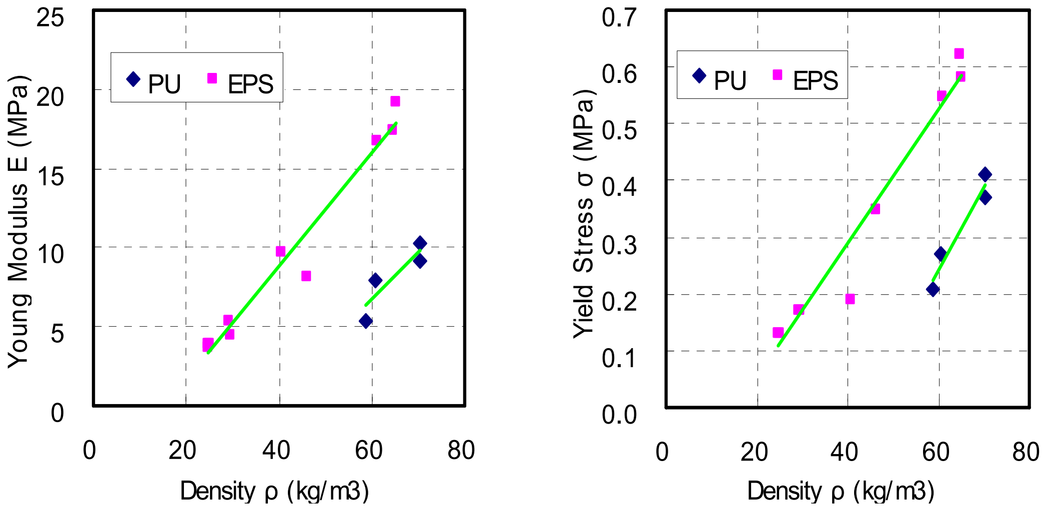

Fig. 7. The Relationship between the Young Modulus or Yield Stress and the Density

The young modulus and yield stress could be determined from the stress- strain curves from Fig. 4 to Fig. 6. It was found that the yield stress and young modulus are linear and proportional to the densities, as shown in Fig. 7. These properties for the hard PU were not evaluated because it was too rigid to apply to the small transportation package. The density range of this graph is about 20 – 70 kg/m^3. Linear equations could be determined from the experimental data points. The young modulus and yield stress of the arbitrary density can be predicted by using these equations. The related equations for the soft polyurethane foam and Styrofoam are as follows.

Styrofoam : $E = 0.3569\rho - 5.4018$, $\sigma_y = 0.118\rho - 0.1811$

Soft polyurethane foam : $E = 0.306\rho - 11.7$, $\sigma_y = 0.0146\rho - 0.6317$

SHOCK ABSORBING EFFECT FOR A SMALL TRANSPORTATION PACKAGE

In a package design of a shock absorber, it is important to determine the selection of the shock absorbing material and its appropriate size in order to reduce the impact force of the package body. Drop energy of the transportation package should be dissipated by the elastic and plastic strain energy of the shock absorber. In order to evaluate the shock absorbing effect for a small transportation package, a 3-dimensional truss model was applied. It was supposed that the sizes of the shock absorber are 40 mm in diameter and 25 mm in height and the model weight of a small package is 750 gram. This upper size is available for transporting a vial which can be loaded with a liquid radioactive material. The load was input as 13.2 m/s equivalent to a 9 m drop condition. The plastic strains and stresses in Figs 4 – 6 were applied. Dynamic analysis was performed by using the ABAQUS/EXPLICIT code.[4] This analysis focussed on the reaction force. This reaction force is one of the important parameters to evaluate the structural integrity. Fig. 8 shows that the reaction forces do not vary proportionally with the densities. The minimum reaction force was determined for any density.

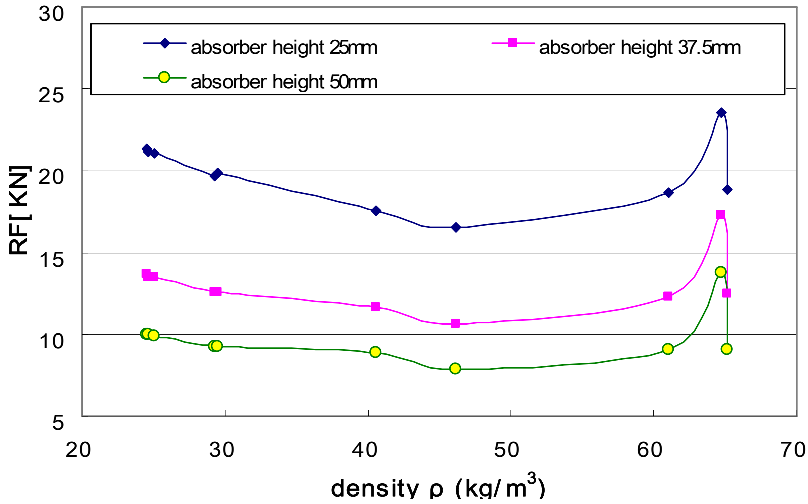

Fig. 8 Reaction Force according to the density

CONCLUSIONS

The small transportation package of the liquid radioactive materials is satisfied for the 9 m drop conditions. The shock absorbing materials of PU and Styrofoam are appropriate for the small transportation package. It was concluded that the conceptual design for the drop conditions could be performed easily by using the stress-strain curves according to the densities.

REFERENCES

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[3] ASTM D1621-00, Standard Test for Compressive Properties of Rigid Cellular Plastics, American Society for Testing and Materials, 2000

[4] ABAQUS ver. 6.4, Analysis User's Manual, ABAQUS Inc., 2003