# Study of Energy Absorption of Combined Model of Cylindrical Compression-Expansion Tube and Thin Cylindrical Tube

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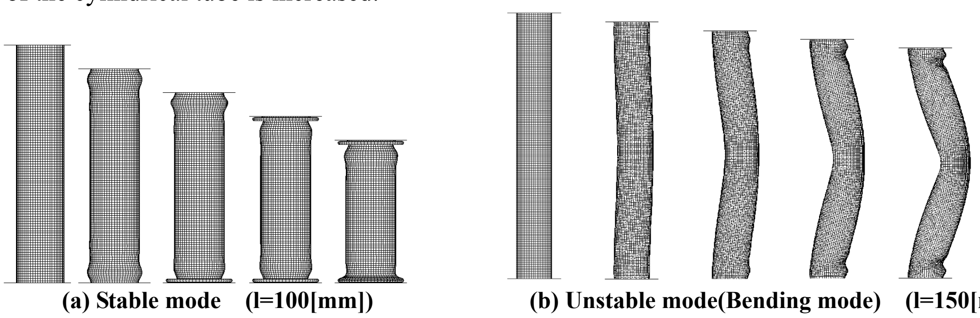
**Abstract:** A thin cylindrical tube that is mainly used as an automotive body structure absorbs energy while generating local wrinkles. Hence, the first peak of the compressive load is produced in the early stages of deformation, and then, the load amplitude is cut. When the length of this tube is increased, no wrinkles are generated, but the Euler buckling on the entire bend is observed and the energy absorption decreases significantly. In this paper, we show that a combination of a cylindrical compression-expansion tube and a thin cylindrical tube favorably affects the energy absorption. Therefore, it is possible to improve the energy absorption of this design.
**Key words:** Crushbox; Cylindrical tube; FEM; Euler buckling

## 1 Introduction

To secure the safety of crew members during a crash accident, thin-walled cylindrical shells are mainly used as automotive body structures. A thin-walled cylindrical shell is required for absorbing the impact strength efficiently at the time of a crash accident. As these thin-walled cylindrical shells, cylindrical or square tubes have been proposed[1]-[7]. When these thin-walled cylindrical shells are compressed, local wrinkles are continuously generated and energy is absorbed. However, there is a disadvantage that the first peak of the compressive load is produced in the early stages of the deformation, and then, the load amplitude is cut. Further, when the length of the tube is increased, no wrinkles are generated but the Euler buckling on the entire bends is observed and the energy absorption decreases significantly. Fig.1 shows an example of the stable and unstable deformation modes of cylindrical tubes (t = 1 [mm], R = 10 [mm]). Fig.2 shows the relationships between displacement and absorbed energy and between displacement and compressive load. A cylindrical tube with a wave is proposed. However, there is a problem that the energy absorption efficiency worsens due to wave processing. Therefore, a new impact absorption member (called cylindrical compression-expansion tube), which is a combination of some short cylindrical tubes, is proposed. By using this cylindrical compression-expansion tube, we ensure that the load amplitude or the peak load in the early stages of modification by the generation of continuous wrinkles is not produced. Therefore, the deformation is stabilized. Hence, in this study, a cylindrical compression-expansion tube and a thin cylindrical tube are combined to control the decrease in the energy absorption by generating the Euler buckling when the length of the cylindrical tube is increased.



**(a) Stable mode (l=100[mm])** **(b) Unstable mode(Bending mode) (l=150[mm])**

**Figure 1 Example of Stable and Unstable Deformation Modes of Cylindrical Tubes (t=1[mm], R=10[mm])**

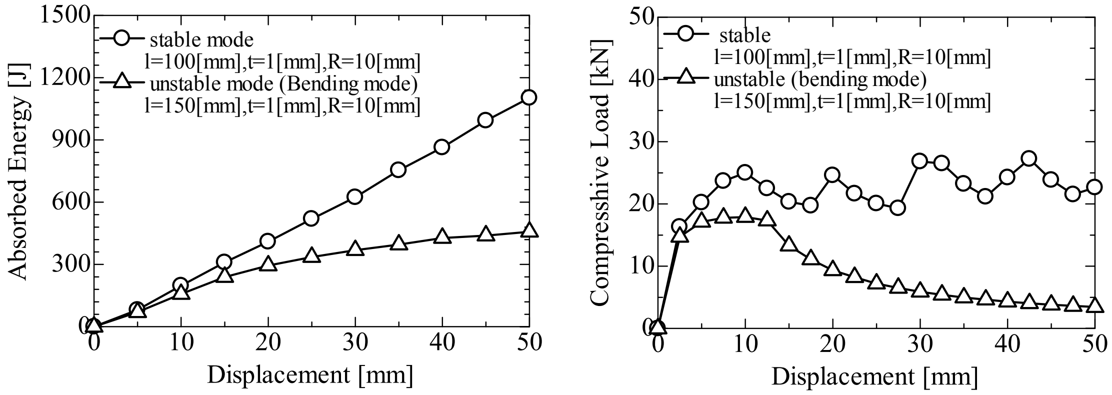



**Figure 2 Relationships Between Displacement and Absorbed Energy and Between Displacement and Compressive Load of Cylindrical Tubes**

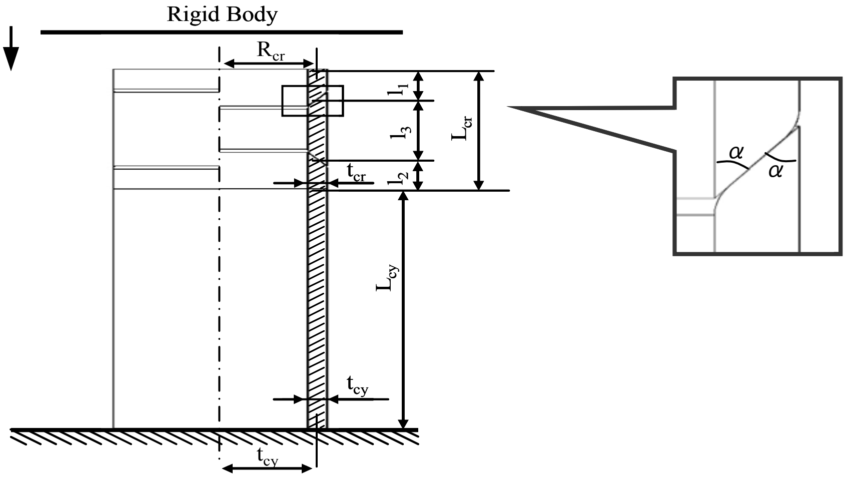



**Figure 3 Analyzed Model**

## 2 Analysis Method

In this study, by using the finite-element-method general-purpose software MSC.Marc, as shown in Fig.3, we consider the lower end of a cylindrical tube to be completely fixed to a rigid wall; a cylindrical compression-expansion tube is fixed on the upper end of a cylindrical tube. An elastic-plastic simulation is performed by using the cylindrical compression-expansion tube. In this study, friction is not considered. Further, the ratio of the length of the cylindrical compression tube and the cylindrical expansion tube is $l_1{:}l_2{:}l_3=1{:}1{:}2$; the fillet is 1.5 times the thickness.

The material properties of the cylindrical compression-expansion tube and the thin cylindrical tube are assumed to meet the Von Mises yield criteria for elasticity-plasticity, homogeneity, and isotropy. Further, the relationship between the stress and the strain is considered to be a straight line, as shown by the following equation:

$$\begin{aligned} \sigma &= E\varepsilon & (\varepsilon < \sigma_y/E) \\ \sigma &= \sigma_y + E_h(\varepsilon - \sigma_y/E) & (\varepsilon > \sigma_y/E) \end{aligned} \tag{1}$$

Where E is Young's modulus, $E_h$ is the work-hardening coefficient, and $\sigma_y$ is the yield stress. Tables 1 and 2 show the dimension of the models and the material properties.

**Table 1 Dimension of Models**

| | Cylindrical Compression-Expansion Tube | | Thin Cylindrical Tube | |
|---|---|---|---|---|
| Length [mm] | $L_{cr}$ | 50 | $L_{cy}$ | 100,150 |
| Thickness [mm] | $t_{cr}$ | 1,2 | $t_{cy}$ | 1 |
| Radius [mm] | $R_{cr}$ | 10 | $R_{cy}$ | 10 |
| Degree of an Angle of Contact | α | 20,30 | | |

**Table 2　Material Properties**

| | Cylindrical Compression-Expansion Tube | Thin Cylindrical Tube |
|---|---|---|
| Young's Modulus E[GPa] | 205.9 | 205.9 |
| Yield Stress $\sigma_y$[MPa] | E/1000 | E/1000 |
| Work-Hardening Coefficient Ratio $E_h$/E | 1/100 | 1/100 |
| Poisson's Ratio $\nu$ | 0.3 | 0.3 |
| Coefficient of Friction $\mu$ | 0 | 0 |

## 3 Analysis Result and Examination: Examination of Combined Model of Cylindrical Compression-Expansion Tube and Thin Cylindrical Tube

A model that combines the cylindrical compression-expansion tube and the thin cylindrical tube is considered. The lengths of the cylindrical compression-expansion tube and of the thin cylindrical tube are determined to 50 [mm] and 100 [mm], respectively, because a 100-mm cylindrical tube is stable and a 150-mm cylindrical tube is unstable. In the case of the 100-mm cylindrical tube, a cylindrical compression-expansion tube is used for compensating for the short length. Moreover, the thickness of the cylindrical compression-expansion tube is set below the initial peak load when the thin cylindrical tube is carrying out the compression buckling. It is examined by using the approximation and the FEM analysis. Fig.4 shows the relationship between displacement and absorbed energy, and displacement and compressive load of the combined model.

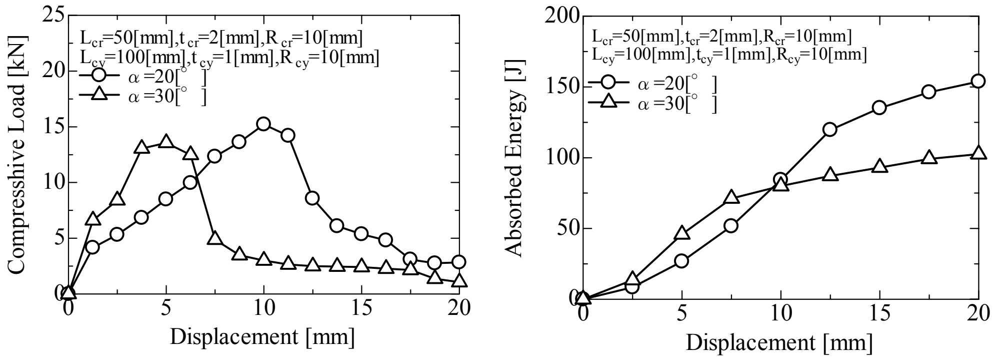



**Figure 4　Relationships Between Displacement and Absorbed Energy and Between Displacement and Compressive Load of Combined Model**

From the results shown in Fig.4, we infer that energy is mainly absorbed in the early stages of crushing. Then, the compressive load decreases significantly and the energy absorption decreases as well. This is attributed to the fact that the cylindrical compression-expansion tube does not crush well. The combination portion is slippery, and the combined model inclines. Therefore, it cannot absorb energy. This phenomenon is not related to the degree of the angle of contact. By decreasing the thickness of the cylindrical compression-expansion tube, the decrease in the energy absorption causing slipperiness is controlled. Fig.5 shows the relationship between displacement and absorbed energy, and displacement and compressive load of cylindrical compression-expansion tubes.

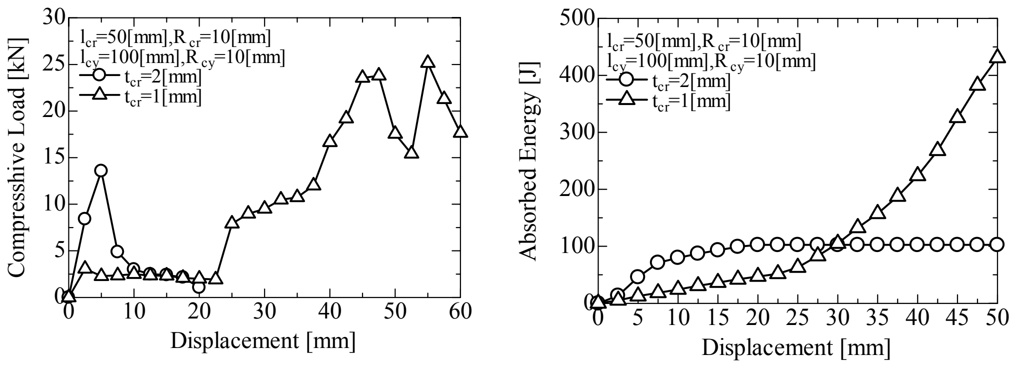



**Figure 5　Relationships Between Displacement and Absorbed Energy and Between Displacement and Compressive Load for Cylindrica Compression-Expansion Tubes**

When the thickness of a cylindrical compression-expansion tube is decreased, although there is little energy absorption in the early stages of crushing, the energy absorption increases with increasing displacement. Fig.6 shows the relationship between displacement and absorbed energy for cylindrical compression-expansion tubes and a thin cylindrical tube.

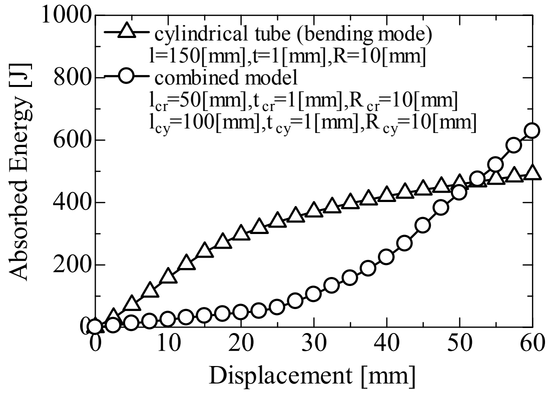



**Figure 6 Relationship Between Displacement and Absorbed Energy for Cylindrical Compression-Expansion Tubes and Thin Cylindrical Tube**

In the early stages of crushing, the cylindrical tube that causes Euler buckling absorbs energy. The displacement of crushing increases and the energy absorption decreases. However, under an opposite condition, the combined model absorbs little energy in the early stages of crushing, and when the displacement of crushing becomes large; a large amount of energy is absorbed. By considering the displacement of crushing, we can use the combined model to control the Euler buckling and improve the energy absorption performance.

## 4 Conclusions

In this study, a combined model of a cylindrical compression-expansion tube and a cylindrical tube was examined. An elastic-plastic numerical analysis was conducted to control the decrease in the energy absorption brought about by Euler buckling. The following points were clarified by the analysis result:

(1) In the case of some dimensions of the models, slipperiness was observed in a cylindrical compression-expansion tube. Therefore, the energy absorption sometimes decreased significantly.

(2) By changing the thickness of the compression-expansion cylindrical tube, we could control the tube's slipperiness.

(3) To obtain the stable deformation the thickness of the cylindrical compression-expansion tube was decreased; although a small amount of energy was absorbed in the early stages of crushing, the amount of energy absorbed increased with an increase in the displacement of the crushing.

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