Axially Crushed Characteristics of Compact Impact Absorption Member

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Abstract: In this study, crushing behaviors of Compact Impact Absorption Member subjected to axial compression are studied by using Finite Element Method and Experiments. A multiple combination impact absorption member referred as Compact-Expand Member was proposed to substitute the conventional thin-walled circular tube. It was found that the proposed Compact Impact Absorption Member has stable load increase characteristics and a wide range of high Load Efficiency (Pave/Pmax) compared to the thin-walled circular tube. Moreover, the proposed Compact Impact Absorption Member is able to absorb a larger load than the thin-walled circular tube because its thickness can be increased even in a small radius.

Key Words: Axial Collapse; Finite Element Method; Compact Impact Absorption; Thin Circular Tube

1 Introduction

From the demands for lightweight car and improvement of crews safety during collision accident, a variety of thin-walled tubular members [(1) ~ (12)] have been proposed as the car's frontal part structure. However, as shown on Figure 1, for most of the thin-walled cylindrical tubes, energy are absorbed by strain caused by a continuous bending and expanding deformation of the plastic hinge part which occurred during the fold formation . This resulted in a bellow-shape deformation that brings a high first peak load and high load amplitude. Moreover, it is difficult for cylindrical and square tubes to withstand a large load in a small diameter since reducing the radius would cause a bending collapse so if increasing the thickness would make the formation of local wrinkle becomes harder. Thus, it is unlikely for them to be used as an impact absorbing member. Therefore, in this study, a multiple combination member (afterward referred as compress-expand member) which is considered able to receive a large load in small radius when compared to thin-walled cylindrical tube is proposed and its properties are investigated.

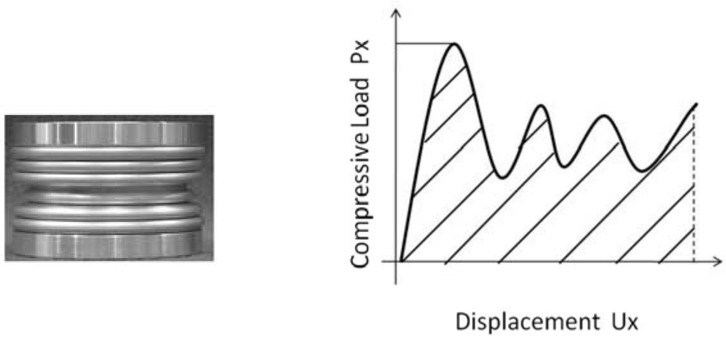

Figure 1 Typical Compressive Load-Displacement Curve for Circular Tube

2 Experiment and Result

An axial crushing experiment by using three types of compress-expand test specimen were conducted. The laboratory equipment used was a Shimadzu hydraulic control all-purpose test machine equipped with a laser displacement sensor. The load-crushing displacement curves are obtained from the Load, Displacement Memory analyzer. In Figure 2, the axial load P_x and displacement U_x obtained from the axial crushing experiment for compress-expand member 1(TP1) and 2(TP2) are shown. Figure 3 shows the deformation diagram of member 2(TP2).

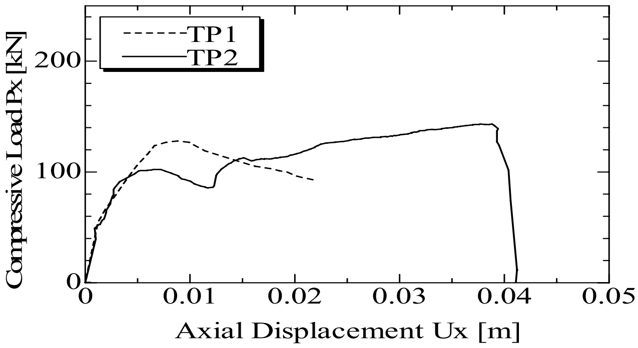

Figure 2 Load-Deflection Curve for TP1 and TP2

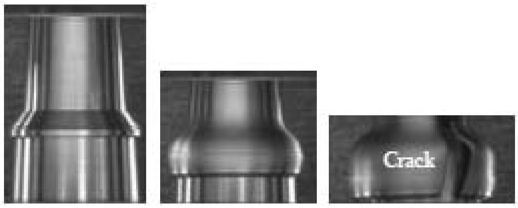

Figure 3 Deformation of the TP2 under Axial Crushing

Then, Figure 4 shows the relation between load and displacement for compress-expand member 3(TP3) where the deformation behavior obtained from the actual evaluatedexperiment and analysis result from FEM are put together. For compress-expand member 1, an insufficient penetration has caused a local collapse to occur thus the test was cancelled. Next, for compress-expand member 2, a continuous expanding deformation has brought a monotonous increase in load and stable load-displacement relation. However, during the expanding process, the rise in circumferential strain has led an axial crack to occur at the expand member's surface. Overall, in this study it is understood that the deformation of the compress-expand members obtained from the axial crushing experiment is consistent with the deformation diagram obtained from FEM.

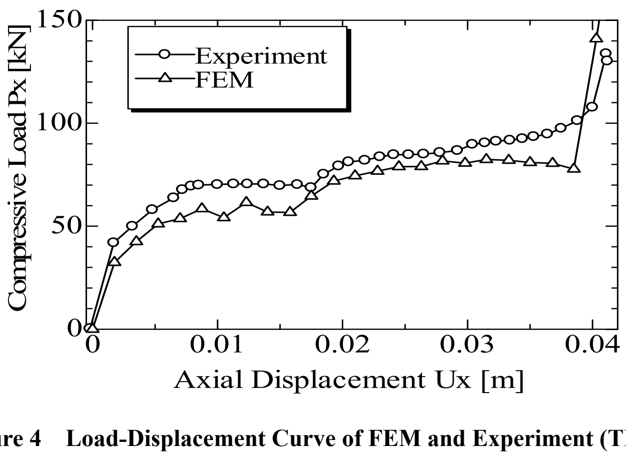

Figure 4 Load-Displacement Curve of FEM and Experiment (TP3)

3 Analysis Result and Investigation

3.1 Investigation of load efficiency

An investigation by FEM concerning the relation of length-thickness ratio L/t to the load efficiency and the nondimensionalized thickness ratio t/R when the value of L/t is changed from 20, 30, 40 until 60 are conducted to clarify the energy absorption properties of the compress-expand member. Here, the energy absorption efficiency is the product of average load divided with peak load (Pave/Pmax). From the result shown in Figure 5, it is known that for a wide range of t/R, load efficiency becomes higher as the L/t becomes larger.

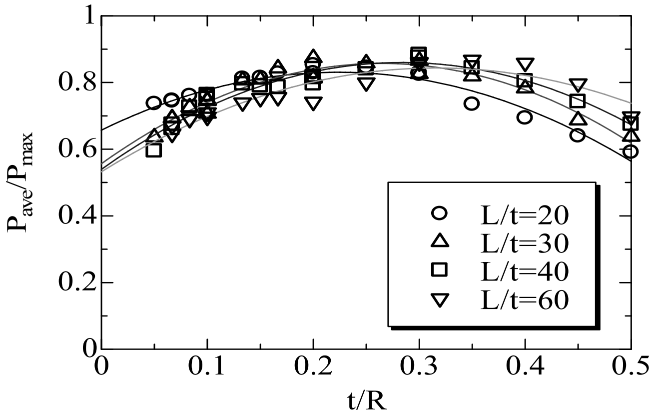

Figure 5 Relations Between Pave/Pmax and t/R

3.2 Investigation of load efficiency for cylindrical tubes and compress-expand members

To conduct the investigation of load efficiency for cylindrical tubes and compress-expand members, the radius and length for both components are set to be equal where R=20 [mm] and L/t = 20. Figure 6 shows the analysis result for load efficiency and radius-thickness ratio t/R relation when thickness t is changed. As shown on Figure 6, for cylindrical tubes, Load efficiency becomes peak at relatively thin thickness t/R=0.1. However, the load efficiency significantly decreases as the thickness increased. On the other hand, compress-expand members show high load efficiency at t/R=0.15~0.30 range. The load efficiency declination is also smaller if compared to the cylindrical tubes. Concerning this matter, Axial crushing analyses are done to cylindrical tube with geometry dimension t/R=0.1 and compress-expand member with geometry dimension t/R=0.3 where these are the dimension when their load efficiencies are at peak.

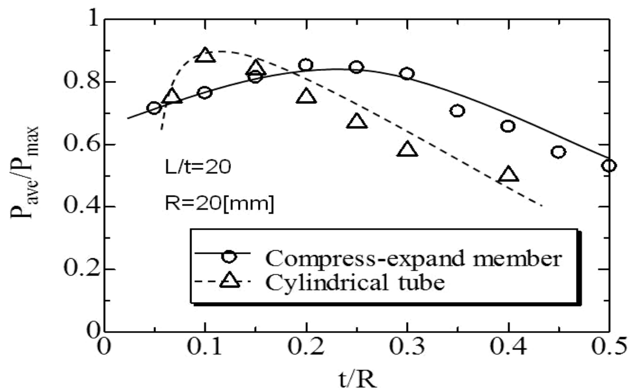

Figure 6 Relationship between P and Tube Thickness- to-Radius Ratio t/R of Compact Absorption Tube and Thin Circular Tube

The compression load and strain curve diagrams obtained from the analysis are shown on Figure 7. From the diagram, it is known that compress-expand members can have a larger t/R if compared to the cylindrical tube which mean that the thickness can be expanded even in a small radius. Thus it is possible for the compress-expand members to receive larger load and have higher load efficiency compared to cylindrical tubes. However, as the compress-expand members are in the range where t/R is over 0.4, it is discovered that a local buckling occurred near the contact area of compression member’s body.

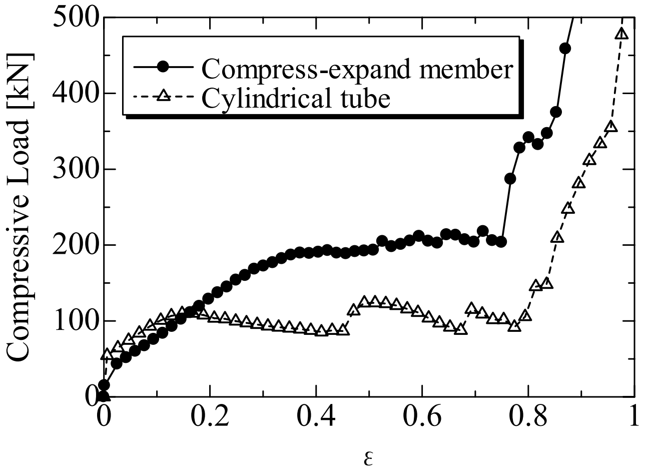

Figure 7 Compression Load and Strain Curve for Compact Absorption Tube and Thin Circular Tube

4 Conclusions

In this study, an investigation upon the proposed compress-expand member has been done by performing both axial crushing experiment of the actual test specimens and theoretical analysis using FEM. Regarding the impact absorption properties of the compress-expand member, the conclusion as shown below have been achieved.

(1) A small load amplitude, monotonous load increase and stable load-displacement relation can be obtained in the axial crushing of compress-expand member.

(2) A compress-expand member can obtain a high load efficiency in a thick-small radius compared to the cylindrical tubes. Moreover, by increasing the radius difference between expanding component and compress component, the compress-expand member can receive large axial crushing load.

References

[1] Alexander J. M. An Approximate Analysis of the Collapse of Thin Cylindrical Shells under Axial Loading[J]. Quarterly Journal of Mechanics and Applied Mathematics, 1960,13 (1): 10-15

[2] T. Wierzbicki, S. U. Bhat, W. Abramowicz, D. Brodkin. Alexander Revisited-A Two Folding Elements Model of Progressive Crushing of Tubes[J]. International Journal of Solids and Structures, 1992, 29(24): 3269-3288

[3] W. Abramowicz, N. Jones. Dynamic Progressive Buckling of Circular And Square Tubes[J]. International Journal of Impact Engineering, 1986, 4(4):243-270

[4] Abramowicz W., Jones N. Dynamic Axial Crushing of Circular Tubes[J]. International Journal of Impact Engineering, 1984, 2(3):263-281

[5] Wierbicki T. et al., Alexander Revisited-A Two Folding Elements Model of Progressive Crushing of Tubes[J]. International Journal of Solids and Structures, 1992, 29(24): 3289-3295

[6] K. Ushijima, S. Haruyama, H. Hanawa, D. Chen. Strain Concentration for Cylindrical Tubes subjected to Axial Compression[J]. Transactions of the Japan Society of Mechanical Engineers, 2005, 71(707):1023-1029(In Japanese)

[7] Dai-Heng Chen, Kenichi Masuda. Deformation Modes for Axial Crushing of Cylindrical Tubes Considered of the Edge Effect[J]. Transactions of the Japan Society of Mechanical Engineers, 2007, 73(773):1029-1036 (In Japanese)

[8] T. Hiratsuka, D. Chen and K. Ushijima. Axially Compression of Corrugated Cylinder, The Society of Automotive Engineers of Japan, Paper No.20055304

[9] D. Chen, T. Hiratsuka. Study of Axially Crushed Cylindrical Tubes with Corrugated Surface Based on Numerical Analysis[J]. Transactions of the Japan Society of Mechanical Engineers, (In Japanese), 2006, 72(722): 1464-1471

[10] K. Ushijima, S. Haruyama, et al. Study on Axially Crushed Cylindrical Tubes with Grooved Surface[J]. Transactions of the Japan Society of Mechanical Engineers, 2005, 71(707): 1015-1022 (In Japanese)

[11] K. Ushijima, S. Haruyama, et al. Strain Concentration for Cylindrical Tubes subjected to Axial

Compression[J]. Transactions of the Japan Society of Mechanical Engineers, 2005, 71(707):1023-1029 (In Japanese)

[12] Dai-Heng Chen et al. Crushing Behaviour of Hexagonal Thin-Walled Tube with Partition Plates[J]. Transactions of the Japan Society of Mechanical Engineers, 2006, 72(724):1978-1984(In Japanese)