



# **ENERGY ABSORPTION PERFORMANCE OF PRESS-FORMED SHELL**

**プレス成形シェルのエネルギー吸収特性**

by  
**ZUBAIR BIN KHALIL**

A Thesis Submitted to the  
Graduate School of Engineering, Gifu University  
as a Partial Fulfillment of the  
Requirements for the degree of  
**DOCTOR OF ENGINEERING**  
(March 2016)

**Supervisor:**  
**Prof. Dr. Minoru Yamashita**

# CONTENTS

<b>Acknowledgement .....</b>	<b>i</b>
<b>Summary .....</b>	<b>ii</b>
<b>Chapter 1: Introduction .....</b>	<b>1</b>
1.1 Background and Objectives .....	1
1.2 Contents of thesis .....	5
<b>Chapter 2: Deformation Behavior of Press Formed Shell by Indentation and Its Numerical Simulation (Hindawi Publishing, Journal of Engineering, Vol. 2015 (2015), Article ID 453931) [34] .....</b>	<b>6</b>
2.1 Introduction .....	6
2.2 Test material and experimental conditions .....	6
2.3 Experimental results and discussions .....	10
2.4 Numerical simulation .....	15
2.4.1 Computational conditions .....	15
2.4.2 Computational results and discussions .....	18
2.5 Conclusions .....	25
<b>Chapter 3: Energy Absorption Performance of Press-Formed Shell under Impact (Elsevier, Procedia Engineering, Vol. 81(2014), pp. 951-956) [35] ...</b>	<b>26</b>
3.1 Introduction .....	26
3.2 Test material and experimental procedure .....	26
3.3 Experimental results and discussions .....	32
3.4 Energy performance evaluation .....	43
3.5 Conclusions .....	47
<b>Chapter 4: General Conclusions .....</b>	<b>48</b>
<b>References .....</b>	<b>50</b>

## Summary

Automobile body usually comprises many sheet metal components. Most of them are usually fabricated by various press-forming operations from sheet metal. The body designers will consider not only the strength for durability but also the structural ability to protect the occupants during impact in a collision event. Sheet metal components are collapsible and this plays an important role as the shock absorber of the kinetic energy exploit plastic deformation. Shape and material of each part and the loading condition, etc. affect the deformation behavior at collision. Thus the main objective of this thesis is to obtain the basic information in constructing the guidelines when designing energy absorber. This is done by studying several simple conditions in energy absorbing deformation behavior.

In the thesis, two kinds of dome shaped shells made by press-forming were deformed by indentation of the simple shaped indentors. Effects on the shell shape, height and the indenter shape in the deformation behavior were then investigated. The objective is to show the fundamental effective information for crashworthy design of press-formed sheet metal parts. The dome shaped specimen was flat-top or hemispherical axisymmetric shell. This was produced by press-forming operation using a circular blank of aluminum alloy A5052. The head shape of the indenter was flat or hemispherical. Numerical simulation was also conducted to predict the deformation patterns and the forces in the press-forming and the indentation using the dynamic explicit finite element code DYNA3D (Public domain version). The energy absorption performance of the shell was evaluated as the consumed energy by the deformation where the indenter travelled up to the length equal to the shell height. The most effective deformation condition for such performance was obtained in the deformation of flat-top shell by flat-headed indenter. Rising tendency in indentation force was duller, when the hemispherical-headed indenter was applied, in contrast to the case where a flat-headed indenter was used. A peculiar crushing load characteristic was observed, when the load was increased, and then decreased for the combination of hemispherical shell and flat-headed indenter. Plastic buckling occurred due to the radial compressive stress upon the material contact to the flat part of the indenter. These phenomena were successfully reproduced in the numerical simulation. Further, when the Bauschinger effect of the material was appropriately introduced into the numerical simulation, the indentation force became closer to the experimental result.

In addition, experiment was also conducted on mild steel SPCE sheets using flat or hemispherical headed indenter under impact condition using a drop hammer or quasi-static one. As a result, several characteristic force variations appeared. Almost flat indentation force is available in the combination of hemispherical shell and round headed indenter. The in-plane compressive stress field in the material induces the increase in indentation force, which in turn increases the energy absorption capacity. The force in impact test of SPCE was approximately 1.5 times higher than that in quasi-static test. The experimental results obtained here implies that the strain-rate effect on the stress tends to be enhanced if the loading direction alters. On the other hand, when we compared the results to aluminium alloy A5052-H34, it did not show the same tendency as SPCE. Aluminum alloy A5052-H34 and mild steel SPCE have comparable performance in energy absorption under impact in the range of the present experiments. The positive strain-rate effect of SPCE under the reverse in loading direction may improve the performance. When comparing the energy absorption performance under impact for the 10 mm diameter indenter with the 30 mm one, the energy absorption performance of 10 mm indenter is around 20 % larger. The reason was because the concentrated indentation force by the indenter caused severe bending to the shell's wall, thus increasing the load to a higher level within the fracture limit of the shell height.

In the present study, several basic characteristics in the indentation behavior were revealed for the simple collapse conditions, thus providing some helpful guidelines in designing the collapsible parts and structures.

effect becomes very remarkable in the present study, where the loading direction is reversed to that in the forming process.

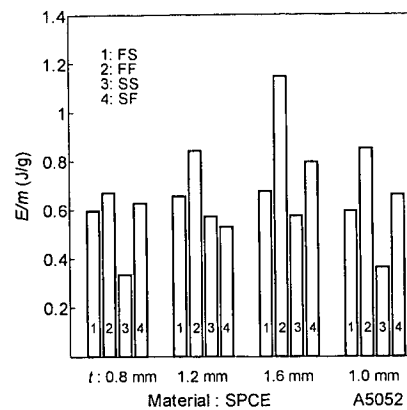


Fig. 7. Energy absorption performance considering mass of shell.

#### 4. Conclusions

The press formed flat top or hemispherical shell was indented using flat or round headed indenter. Mild steel SPCE or aluminum alloy aluminum alloy A5052 shells were tested under impact or quasi-static deformation condition. The main conclusions are as follows:

Several characteristic force variations appeared. Almost flat indentation force is available in the combination of hemispherical shell and round headed indenter. The in-plane compressive stress field in the material induces the increase in indentation force, which increases the energy absorption capacity.

The force in impact test of SPCE was approximately 1.5 times higher than that in quasi-static test. The experimental result obtained here implies that the strain-rate effect on the stress tends to be enhanced if the loading direction alters. On the other, aluminium alloy did not show the tendency.

Aluminum alloy A5052-H34 and mild steel SPCE have comparable performance in energy absorption under impact in the range of the present experiments. The positive strain-rate effect of SPCE under the reverse in loading direction may improve the performance.

#### References

- [1] Alghamdi, A., 2001. Collapsible impact energy absorbers: an overview. *Thin-Walled Structures* 39, 189-213.
- [2] Alghamdi, A., 2002. Reinversion of aluminium frusta, *Thin-Walled Structures* 40, 1037-1049.
- [3] Bisagni, C., 2002. Crashworthiness of helicopter subfloor structures. *International Journal of Impact Engineering* 27, 1067-1082.
- [4] Dong, X., Gao, Z., Yu, T., 2008. Dynamic crushing of thin-walled spheres: An experimental study, *International Journal of Impact Engineering* 35, 717-726.
- [5] Olabi, A., Morris, E., Hashmi, M., 2007. Metallic tube type energy absorbers: A synopsis. *Thin-Walled Structures* 45, 706-726.
- [6] Shariati, M., Allahbakhsh, H., 2010. Numerical and experimental investigations on the buckling of steel semi-spherical shells under various loadings. *Thin-Walled Structures* 48, 620-628.
- [7] Zupana, M., Chen, C., Fleck, N., 2003. The plastic collapse and energy absorption capacity of egg-box panels. *International Journal of Mechanical Sciences* 45, 851-871.