Fast Fine Simulation for Side Crashworthiness of a Passenger Car

LI Hongjian[1], HU Ping[2], LIU Jie[2], PAN Zuofeng[1], TANG hongbin[1], QIU Shaobo[1]

[1]*R&D Center, FAW*
[2]*Jilin University*

Abstract – The changes of characteristics of material and geometry caused by stamping all influence the precision of CAE. This thesis shows that a typical structure and a full car model were built using one step forming and mapping method based on VPG and KMAS software，thus enabling us to define it Fast Fine Simulation method (FFS); likewise, the pure static bend test and the side impact test complied with FMVSS214 were respectively completed. FFS result shows better consistency with the result of the test and, at the same time, it can reduce a lot of calculation cycles.

Keywords: Fast Fine Simulation, Side Impact, One Step Forming

1 Introduction

Reverse engineering was utilized by Gupta[1] and Gonzalez [2] using the collection of techniques to re-create the original specifications out of a totally finished product in order to contain a robust and accurate FEM model. Reverse engineering is a detailed simulation analysis, although it brings a great amount of works to rebuild the model. Forming simulation analysis can obtain thickness changes, working hardening, residual stresses, etc. Integration of the results of sheet forming simulation in crashworthiness was carried out by Cajuhi[3] and Abrantes[4]. These two technologies will bring out a large amount of calculation cycles, but FFS method can overcome this shortcoming and keep a relatively higher precision as well.

2 One Step Forming Method

One step forming method is a FE algorithm to implement the panel stamp at one step only based on total theory. Initial and final situations were considered, regardless of the process in calculation. It can be expressed by virtual work function as follows[5]:

$$W = \sum_e W_{\text{int}}^e - \sum_e W_{ext}^e = \sum_e \left(\int_{v^e} \{\varepsilon^*\}^T \{\sigma\} dv - \int_{A^e} \{u^*\}^T \{f\} dA \right) = 0 \qquad (1)$$

Where W_{int}^e , W_{ext}^e are, respectively, inner and outer virtual work of element; $\{u^*\}$, $\{\varepsilon^*\}$ are, respectively, virtual displacement and virtual strain; $\{f\}$ refers to outer force.

Function (1) cannot be strictly satisfied in calculation. Herein below is the difference of inner force and outer force (residual force) that is defined as $\{R(u)\}$

$$\{R(u)\} = \{F_{ext}(u)\} - \{F_{\text{int}}(u)\} \neq 0 \qquad (2)$$

Where $\{F_{ext}(u)\}, \{F_{\text{int}}(u)\}$ are node vectors of outer force and inner force.

Function (2)’s Newton-Raphson iterative form becomes the following form of[6]:

$$[K_T(u^i)]\{\Delta u^i\} = \{R(u^i)\}, \quad \{u^{i+1}\} = \{u^i\} + \omega\{\Delta u^i\} \qquad (3)$$

In which, ω is iterative constringency factor; $[K_T(u^i)]$ is tangent stiffness matrix of i^{th} iteration

Contact E-mail: lihongjian@rdc.faw.com.cn

and it can be expressed in global coordinate as

$$K_T(u)=\left[-\frac{\partial\{R(u)\}}{\partial\delta\{u\}}\right]_{u=\{u^i\}} \tag{4}$$

3 Simulation and Test of Typical Structure

A closed box part was designed for impact test and simulation abstracted from typical structure of car body. The length of this part corresponds to 250mm. and the interval of two spot welds is 40mm. Stamping and bending methods was used to make these parts. Stamping die was made of low melting point metal and it can ensure the exact dimension, as showed in fig. 1. The part was made by the bending machine and the main contour has been saved except the radii complied with the machine radius, as showed in fig.2.

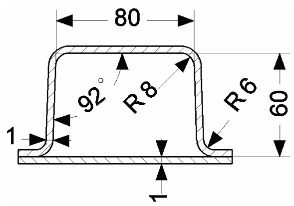


Fig.1 Section of stamping part

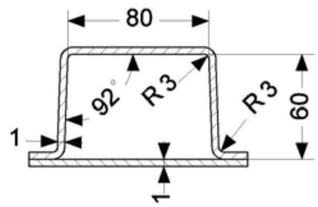


Fig. 2 Section of bending part

In this thesis, Electric Universal Puller was used to measure the material property in order to up-grade the simulation precision. Fig.3 shows the relationship of stress and strain. There is an obvious hardening phenomenon shown in this figure.

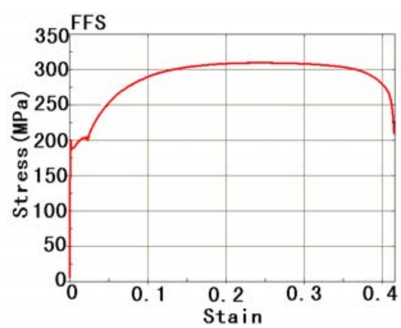


Fig. 3 Stress vs. strain

The maps of thickness changes and residual strain making by One Step Forming on KMAS are showed in fig.4 and fig.5.

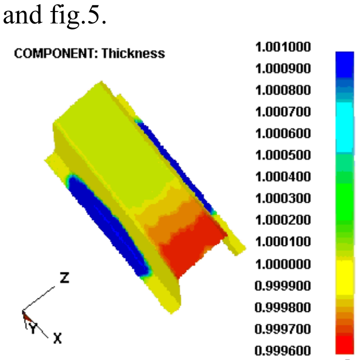


Fig. 4 Thickness distribution

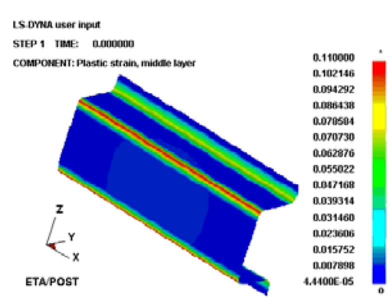
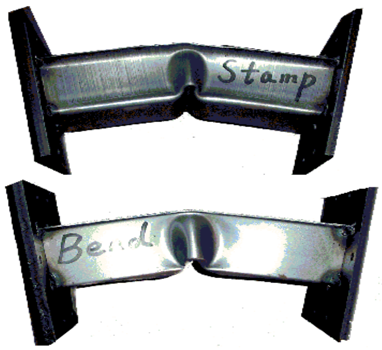


Fig.5 Plastic Strain distribution

Pure bending tests were fulfilled by using a special bending facility. The bending deformations of parts made by two different methods showed in fig.6. A group of curves of moment vs. rotation angle was calculated by this facility shown in fig.7 and fig.8. There are a significant discrepancy between stamping and bending parts and an improvement by means of a more accurate definition of material properties. Fig.7 showed that high consistency of M(θ) relationship between experiment and simulation was increased by 10% considering forming effects. FFS is a feasible method validated through the herein above described analysis.



Stamping Part

Bending Part

Fig. 6 Deformation after bending test

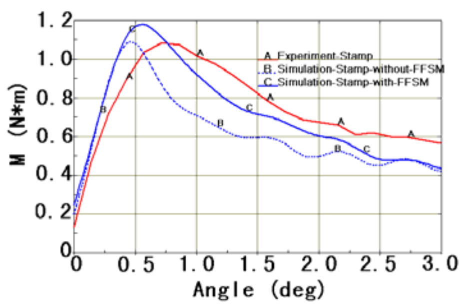


Fig. 7 The Effect of FFSM

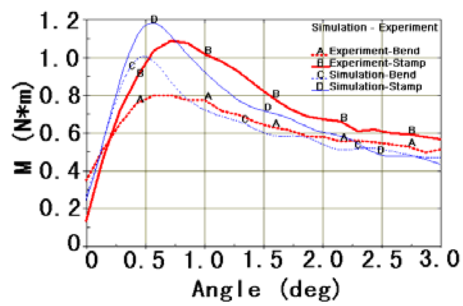


Fig.8 Comparison of Simulation and Experiment

4 FFS for Side Crashworthiness of a Passenger car

The FE model for side crashworthiness was built by using VPG software and the model data is included in Table 1.

Table 1 FE Information

Number of parts	412
Number of nodes	414164
Number of beam elements	2190
Number of shell elements	400241
Number of solid elements	8888
Number of spot-welds	48
Number of nodal rigid body constraints	7002
Number of joints	79

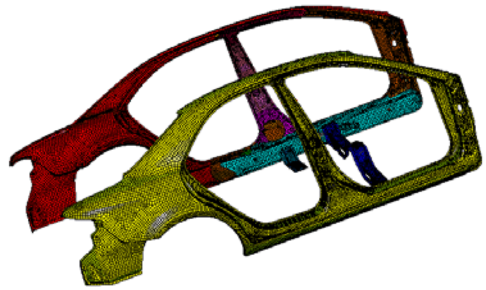


Fig. 9　Side component formed by KMAS

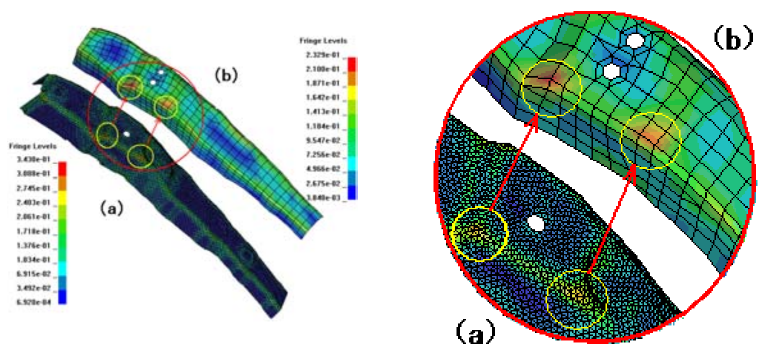


Fig.10　Mapping of plastic strain changing on bending model (a) from the stamping model (b)

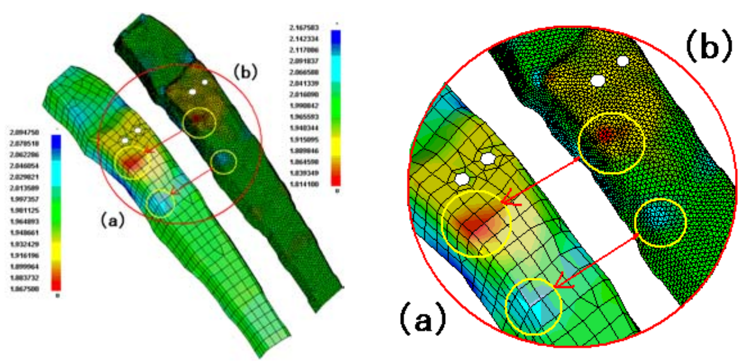


Fig.11　Mapping of thickness changing on bending model (a) from the stamping model (b)

Some parts – that significantly influence the result of side crashworthiness - were analyzed using one step forming shown in fig. 9. One step forming can quickly obtain the thickness changing, the residual strain, etc. and it always has a relative high precision as far as the parts shown in fig. 9 are concerned. Forming results and mapping process of B-pillar inner panel are shown in fig.10 and fig.11. Deformation and acceleration curves considering or not material effects is specifically presented in fig.12 and fig.13.

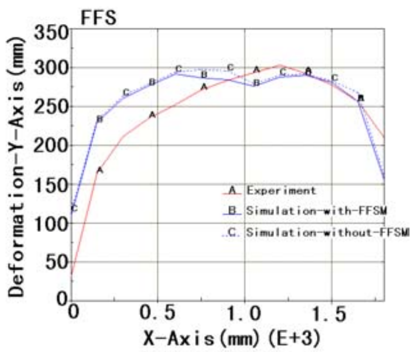


Fig.12 Deformation of side panels at H-point level

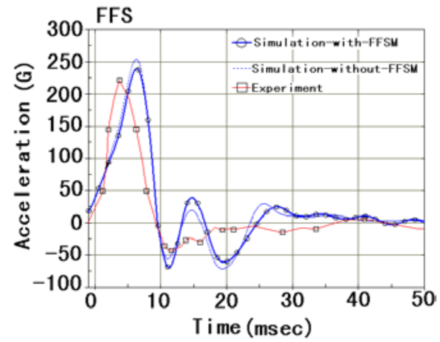


Fig.13 B pillar acceleration

A good agreement between simulation and experiment - taking into consideration the forming effects - was carried out as shown in fig.12 and fig.13. The comparison between NCAP experiment and simulation shows that crash simulation - using FFS method - can improve the precision by 8% compared to the traditional method.

5 Conclusion

In this paper, FFS method combined VPG with KMAS software was proposed to deal with side crashworthiness. It has been demonstrated that the accuracy of crash simulation enclosed stamped body parts can be significantly improved by considering material effects generated from one step forming simulation. Compared with traditional crash analysis, at least 8% accuracy was achieved for the case of this study. The methodology presented in this paper can provide more accurate information for constraint system optimization based on a good comprehension of the impulses, of the peak and of the process of acceleration, as well as of the deformation and of the energy management. More accurate input can also reduce the works of next process within a crash research.

6 Reference

1. Gupta, V., Gunasekar, T. J., Rao, A., Kamarajan, J. and Summer S. “Reverse Engineering Method for Developing Passenger Vehicle Finite Element Models”. SAE Paper 1999-01-0083.
2. Monclus-Gonzalez, J., Kan C .D. and. Bedewi N. E. “Versatility and Limitations of a Fully Detailed Finite Element Model of a 1997 Dodge Grand Caravan for Crashworthiness Applications”. SAE Paper 2000-01-0629.
3. Cajuhi A. J., Romera G. F. S., Adilson Aparecido de Oliveira, Kato G. M. “Forming Analyses Results Influences on Safety Crash Finite-Element Analyses”. SAE Paper 2003-01-3621.
4. Abrantes J.P., Argentino M.A., Antonio Carlos da Costa Gonçalves, José Cássio Mezzetti Correa. “Integrating the Results of Sheet Forming Simulation in Crashworthiness”. SAE Paper 2003-01-3742.
5. Yang Shiyong, Kikuo Nezu. “Application of an Inverse FE Approach in the Concurrent Design of Sheet Stamping”. J.M.Proc.Tech,79(1998).
6. Naceur H. Delaméziere A, Batoz J.L. “Some Improvement on the Optimum Process Design in Deep Drawing Using the Inverse Approach”. J.M.Proc.Tech,146(2004).