Virtual Tryout Technologies for Preparing Automotive Manufacturing

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Abstract

It is important to reduce the weight of the automotive and to shorten the development period for reduction of CO_2 discharge. For these purpose, virtual tryout technologies have been introduced automotive industry. Every process from stamping to assembly for car development has introduced CAD design and numerical simulation such as forming simulation, dimensional accuracy simulation, and so on. In this paper, sheet metal forming simulation and related technologies are presented as a one example of virtual tryout technologies for preparing automotive manufacturing

A total stamping simulation system, which enables advanced study on formability of stamping parts and accuracy of assembled parts, has been developed. It can be applied from vehicle body parts design phase to production preparation phase. The developed system is consisting of 1) simulation technologies to enable parts designers to evaluate function and formability of a part, 2) simulation technologies to enable high precise prediction of dimensions of stamping parts and 3) simulation technologies to obtain parts with high dimensional accuracy after connection of stamping parts with hemming. The system can reduce vehicle development period drastically without reducing dimensional quality of parts.

1. Introduction

Automotive lightening for better mileage to reduce load on the global environment by reduction of CO_2 discharge and for shortening of new model development time frame for timely marketing to meet user's requirement are strongly being progressed now. Aluminum alloy sheets and high-strength steel sheets used for automotive lightening have less workability than regular steel sheets and have larger spring back (deformation due to elasticity recovery after removing parts from forming dies). Therefore, there are many issues which are difficult to solve with current forming know-how. Employment of computer simulation technologies, which can achieve changing forming conditions and die shape in short term freely and is possible to study formability improvement without actual forming trial, is expected. Reduction of trial number before completion of the die for forming by improving quality of die design study in advance is essential to achieve short development term. For these purposes, sheet metal forming simulation technologies are essential.

Conventional sheet metal forming simulation technologies have been applied mainly at the preparation phase of the dies which shape data are available. It has been applied for evaluating limited concerns such as cracks and wrinkles at stamping process and it was not enough to solve the problems cited above.

In order to overcome these problems, a system called "Total Stamping Simulation System" has been developed. It can be applied widely in cars development from parts design phase through production preparation phase for formability evaluation of sheet metal forming parts. In addition to it, the developed system can enlarge formability evaluation range of the stamping parts not only for cracks and wrinkles but also for spring back with increasing accuracy of the results from sheet metal forming simulation. In order to produce excellent quality vehicles, dimensional accuracy of assembled parts is very important. For assembling parts such as doors, hood, trunk and so on, hemming is applied. The developed numerical simulation technologies regarding hemming is also introduced in the system. It can be said that the system can be applied from stamping forming to assembly with hemming, in other words it can be performed from up stream to down stream of stamping parts development.

2. Characteristics of the total stamping simulation system

As mentioned before, the developed sheet forming simulation system can be applied from the design phase to the production preparation phase of vehicle parts. Characteristics of this system are shown below:

2.1 Simulation methodology applicable at design phase of vehicle parts

The formability prediction methodology which simulation can be executed only with parts shape has developed because information on forming process is not enough at parts design phase. This methodology development enabled a parts designer to design parts considering stamping condition together with its function and performance not relying on knowledge of forming engineering.

2.2 Simulation methodology applicable at production preparation phase of vehicle parts

(a) dimension accuracy prediction simulation methodology for stamping parts and (b) hem assembly simulation methodology have also developed. They are applicable at production preparation phase and their characteristics are shown below:

(a)Dimension accuracy prediction simulation for stamping parts

The FEM (finite element method) software together with RIKEN to analyze with high accuracy dimension change after stamping due to spring back has developed. This software can simulate with high accuracy not only steel sheet but also aluminum alloy sheet. We have also developed evaluation methodology for surface deflection.

(b)Assembly simulation methodology for stamping parts by hem forming

Dimension accuracy of not only as a stamping part but also assembly is important for high quality vehicle body production. Hemming often cause deformation of the parts after joining. We have developed simulation engineering to predict this deformation in advance and can apply the developed countermeasure on the part shape and design of the die for hem stamping.

3. Sheet metal formability analysis in parts design phase

We are required to satisfy the formability and function of parts in parts design. It is necessary to prepare not only parts models but also die models when we use the common numerical stamping simulation software which requires a lot of incremental steps. Therefore, a die design is necessary, and it is difficult to execute the analysis within a limited time even to do a brief formability analysis.

On the other hand, one-step methodology does not need a die model. It requires only a parts model and material properties for simulation and also the calculation time is very short. It is suitable for part formability validation in the parts design phase.

In this methodology, it is possible to take into account the material flow effect of outside boundary of the parts by using boundary force. This boundary condition which simulates material flow on the addendum and the die-face is significant in order to get a high accuracy for strain distribution analysis. However in general, the part shape influences the die shape. This means the material flow on the outside of part boundary depends on the parts shape.

Figure 1 shows the basic idea to set an equivalent boundary force to die material flow. Figure 1(a) shows the actual die shape and it is designed with respect to the shape feature and forming direction shown in Fig.1(b). The relational expression that was used to calculate the adequate boundary force shown in Fig.1(c) from the shape feature was constructed. This methodology does not need in-depth knowledge of stamping for the user. This is the reason why a parts designer could study formability by using this methodology.

Figure 2 shows a comparison between the results of an incremental simulation and a one-step simulation of an inner door panel. The thickness distribution for each method is qualitatively the same and it is very profitable for early phase design study.

4. Prediction methodology for dimensional accuracy of stamping parts

Breakage and wrinkling prediction in automotive body stamping parts in the product design stage has enabled the realization of high quality, low cost and short delivery

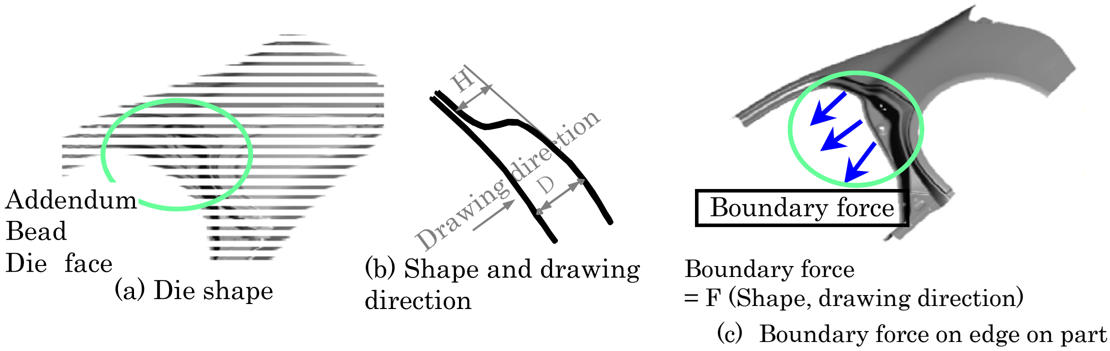


Fig.1 Boundary force setting for one step simulation

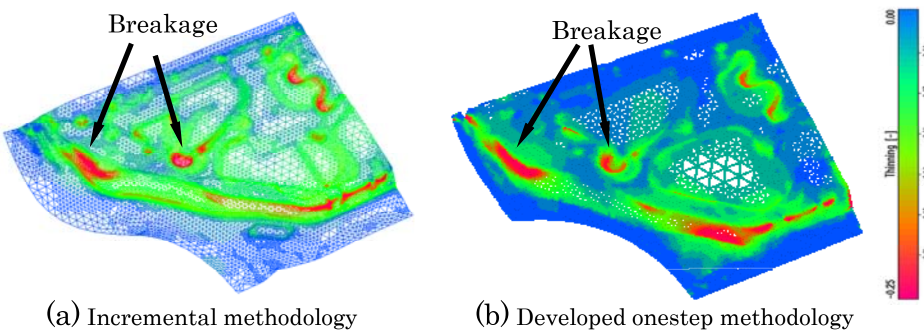


Fig.2 Thickness distribution comparison between simulation methodologies

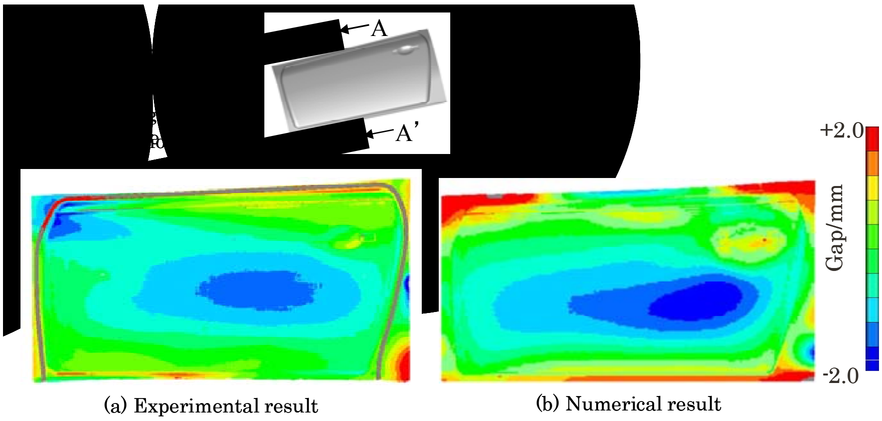


Fig.3 Gap between geometry after drawing and desired shape

periods. However, prediction technologies for shape defects including springback, surface sinkage and surface deflection are not yet established, and thus empirical, time-consuming trial-and-error methods have been used in the production-preparation scheme. There is, therefore, a strong necessity for the establishment of accurate simulation technology to deal with the above problems.

For the purpose of predicting stamping defects caused by springback phenomena, many attempts have been made to apply FEM codes to practical automotive parts with complicated geometry and intricate deformation processes. However, for the calculation time, robustness and quantitative accuracy of the calculation, simulation methods that meet the requirements of the product design phase in the automotive industry have not yet been achieved.

Surface defects, the source of which is considered to be non-uniform stress and strain distribution caused by non-uniform elastic recovery, are closely related with springback phenomena, for which prediction method by simulation are strongly needed.

In this section, several algorithms that improve the accuracy of springback prediction are presented, followed by several examples of its applications to automotive stamping parts.

4.1 Evaluation of accuracy in sheet forming simulations

Algorithms presented in sections 4.1.1 and 4.1.2 were applied to several automotive outer parts, such as door outer and front fender, in which surface defects and dimensional deviation due to springback are the most critical concern.

4.1.1 Prediction of surface dent on door outer panel

Simulations and experiments were performed using the drawing operation of a door outer part. The contour representation in Fig.3 indicates the gap between the geometries of the panel after drawing and the designed ideal shape. Fig.3(a) and (b) show the experimental result measured by a 3D laser scanning machine and the numerical result of springback, respectively. Negative value indicates the surface sinkage at which the geometry became

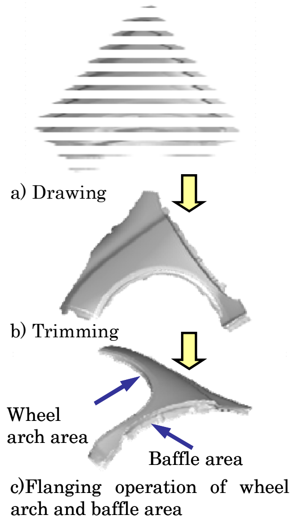


Fig. 4 Multi operation stamping process of front fender panel

flat (went inward of the car body) after springback, while positive value indicates the opposite. The surface sinkage due to springback can be observed on both results quite similarly as dark areas, which correspond to negative gap values of around 2mm.

4.1.2 Simulation of front fender panel in multi-operation stamping process [1][2]

The second application of springback simulation by ITAS3D concerns a front fender panel with a multi-operation stamping process. The stamping process consists of three main operations as shown in Fig.4: drawing, trimming and flanging. For the flanging simulation, the profiles of the cross-section A-A’, as shown in Fig.5, are compared between numerical and experimental results, showing a good quantitative correlation with each other.

The results of above two applications show that the values of geometrical gap between numerical and experimental results were within the standard deviation of 0.5mm, implying that the code can be of practical use for the prediction of springback, followed by die geometry compensation.

4.1.3 Simulation of surface deflection

In order to verify the new methodology, the experiment and the FEM analysis were carried out. Figure 6 shows the results of visual evaluation for experimental panel. Surface deflection defect called ‘Teddy bear ears’ around embossment and surface undulation on flat area were detected.

The evaluation results from RADICAL [3] were shown in Fig.7. Autoform [4] and ITAS-3D [5] were used for simulation. The evaluation direction was the same as the longitudinal direction of the embossment shape. The calculation range L of curvature was 30mm. The yellow color indicates measured data with more concave shape than CAD data, and blue color means measured data with more convex shape than CAD data, confirming that visual evaluation and evaluation with RADICAL are qualitatively similar. Furthermore, it is found that the numerical simulation results are qualitatively the same as the experimental results.

5. Hemming simulation on assembled stamping panels [6]

Car body parts like hoods, trunks, doors are assembled inner/outer stamping panels by hemming process. The hemming process is one of prominent process to connect outer panels with inner panels by bending hem-flange around edge of outer panels. It is possible that assembled panels are deformed as springback phenomena after hemming process due to stress distributions generated at hem-flange elongated or contracted bending based on the shape of bending line. There was no analysis procedure to predict the geometry of assembled panels after hemming process. Therefore, much trial-hour with die repair was required to improve the geometry of assembled panels comparing with CAD geometry in the development of new car body.

Now we have developed hemming simulation to predict the deformation of assembled panels after hemming process. It could be used to study the stregth of stiffness, dimensions of inner/outer panels, hem-flange shape(length/angle), and so on to improve the geometry

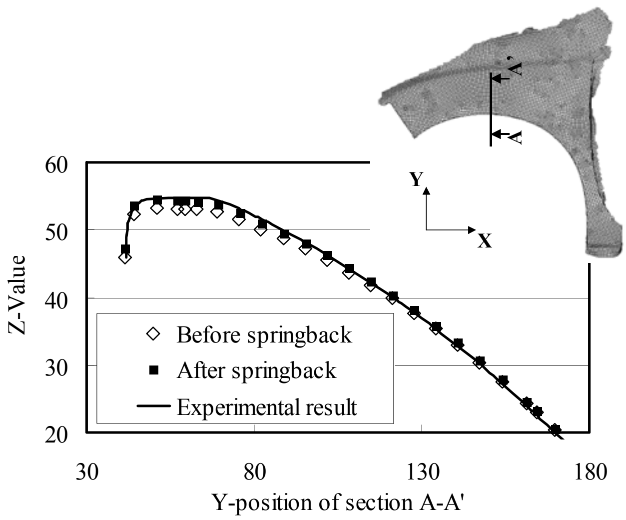


Fig. 5 Comparison of cross-sectional profiles after flanging operation

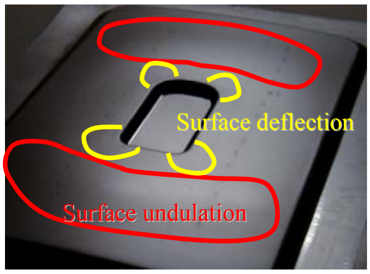
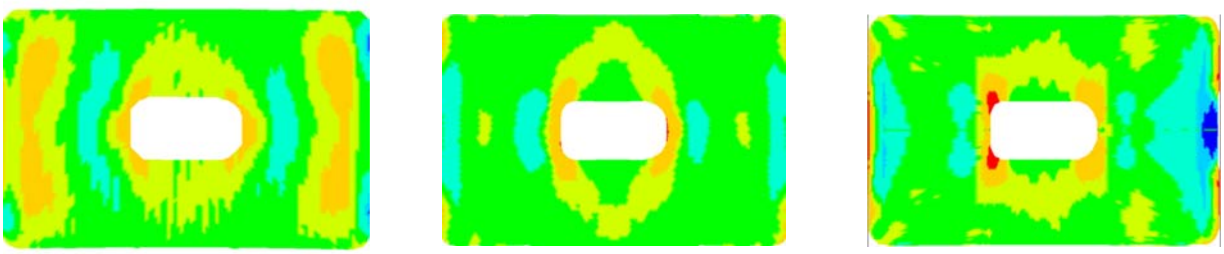


Fig.6 Results of visual evaluation



a) Experiment b) Autoform c) ITAS-3D

Fig. 7 Results of evaluation with RADICAL accuracy of assembled parts by predicting springback after hemming process. By setting appropriate conditions in hemming simulation, the amount of time devoted to modifying the die by trial and error can be reduced.

In hemming simulation, from die closing to die opening process, springback phenomena at die opening after bending hem-flange at die closing are analyzed. The analysis procedure and the verification result for hemming simulation are presented as the followings. Hem analysis model is shown in Fig.8.

(1) Die closing analysis:

Hem-flange of outer panels used to be bent in 2-steps in hemming process. For example, the first step to bend hem-flange of outer panel from 90 to 45 degrees is performed as pre-hemming process, then the second step should be done to bend hem-flange from 45 to 0 degrees as hemming process. The order of hemming simulation is the same way as actual process. In the analysis procedure, contact problem as bending hem-flange of outer panels to tuck inner panels must be solved. Solution of this contact problem needs analysis functions as not only edge-contact in inner/outer panels but also self-contact in outer panels. PAM-CRASH as the dynamic explicit FEM, has the capability to solve the above contact problems. So, we selected PAM-CRASH as analysis solver.

(2) Die opening analysis:

Springback occurs due to stress distributions in the assembled panels from die closing to die opening process. For deformation analysis on this springback, we selected PAM-STAMP having static implicit FEM, which easily shares data with PAM-CRASH as die closing analysis. In general, it is extremely difficult for the static implicit

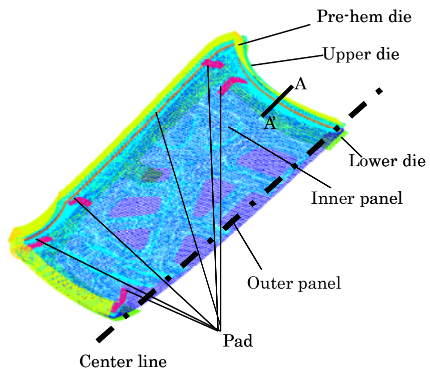


Fig.8 Hem analysis model

analysis to obtain convergence solutions as contact

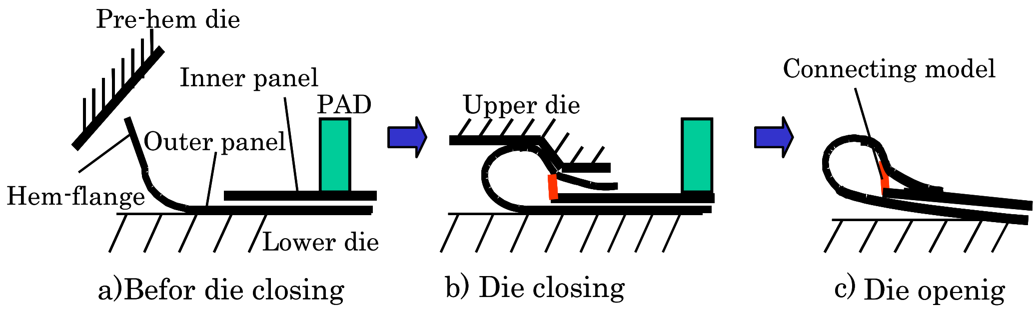


Fig.9 Model at cross section of AA'

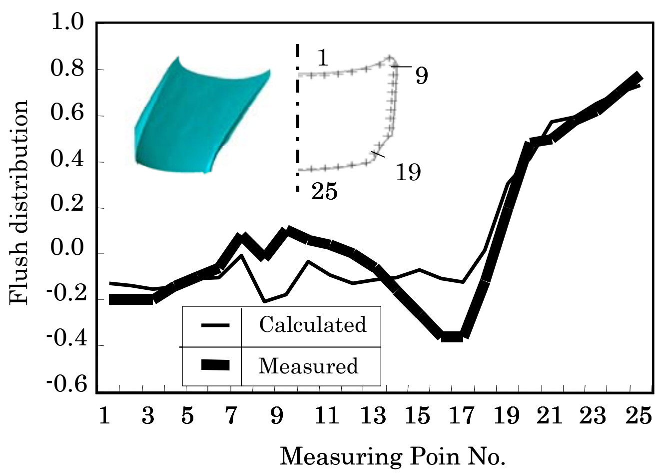


Fig.10 Result of verification using aluminum alloy hood

problems having complex friction phenomena between inner and outer panels. We have developed the modeling method by elasticity bar-elements connecting inner panel edge with hem-flange of outer panels as shown in Fig.9. This enabled to complete calculation within few minutes because of removing complex contact problems.

(3) Verification result:

We obtained flush distributions on the assembled hood geometry obtained by hem simulation results compared with the actual part. Simulation result coincided with measured data very well as show in Fig.10.

6. Summary

It has been introduced technological outline of a total stamping simulation system, which enables advanced study of formability of stamping parts and assembled parts accuracy. It can be applied from vehicle body parts design phase through production preparation phase in vehicle development.

The developed system is consisting of 1) simulation technologies to enable parts designers to evaluate function and formability of a part, 2) simulation technologies to enable high precise prediction of dimensions of stamping parts and 3) simulation technologies to obtain parts with high dimensional accuracy after connection of stamping parts with hem in addition to the current formability advance evaluation of vehicle stamping parts. It is confirmed that the results from every simulation technology coincide with the test results and the system is already applied to the actual operation to contribute shortening of the vehicle development term.

In order to promote efficiency of development in the future, simulation is expected to blossom into the system. It can perform not only as a substitution of trials but also as a automatic searching system of parts and die geometry which can produce parts without defects by integration with the optimization technologies. [7]

References

[1] Takamura, M. Et al., Springback simulation of automotive front fender panel in multi-operation stamping process using static-explicit FEM code, Proc. NUMISHEET 2002, (2002), pp.379-384.

[2] Takamura, M. Et al., Development of Accurate Springback Prediction Technology in Sheet Forming Simulations, FISITA Transactions 2006, (2007-9), F2006M230T(CD-ROM).

[3] Moriya, T. , Takamura, M., Takahashi, S., Terada, K. : Development of total stamping simulation system for evaluating formability of sheet metal forming parts, 30 (2009) pp.449-456

[4] Kubli, W. and Reissner, J., Optimization of sheet-metal forming process using the special-purpose program AUTOFORM, Journal of materials processing technology, Vol.50(1995), pp.292-305.

[5] Kawka, M. and Makinouchi, A., Shell element formulation in the static explicit FEM code for the simulation of sheet stamping, Journal of materials processing technology, Vol.50(1995), pp.105-115.

[6] [6] Terada, K. , Takahashi, S. & Takai, R.: Development and application of the hem simulation (in Japanese), The 58th Japanese Joint Conference for the Technology of Plasticity, (2007), pp.455-456

[7] Moriya, T. & Takahashi, S. : Development of forming condition optimization methodology in the deep drawing process for automotive outer parts, Proc. 9th Int. Conf. Technology of Plasticity (CD-ROM) (2008)