A Study on Scatter during Production Process using Statistical Approach using LS-OPT®

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Abstract

In recent years, robustness of car body structure has become more important than ever, as car manufacturers are required to achieve conflicting performance in high level such as light weight and crash performance. Major source of scatter in body structures are material scatter and production scatter. Since it is difficult to reduce scatter in material as certain range of scatter is allowed by industrial standard, tightening the quality control is not realistic. Only viable solution is to improve production process such as stamping and joining to address the issue. A common way to assess robustness of the structure is to build response surfaces and study sensitivity of input scatter to output, and there are many papers available on the issues. Although most of approaches focus only on input scatter and the final status, direct connection between the initial status and the final status does not give much insight on the mechanism.
In this paper, a statistical approach is introduced by using DIFFCRASH in order to visualize the trigger and path of scatter propagation during stamping process, and the mechanism of scatter propagation during the production process is discussed.

Background

In automotive industry, robustness of car body structure has become more and more important to make sure the product fulfill all the requirements even in worst scenarios. Development cycle has become shorter than ever, and there are no enough safety margins for risk hedge in order to fulfilling multiple requirement which conflicts with each other. On the other hand, Safety requirements are stricter than ever. The major source of scatter in structure is the material and production. One approach is to enhance structural design to mitigate the influence from scatter to the structural performance [1]. However, the less scatter in structural parts and assemblies, the more rooms for design engineers to enhance performance. A conventional approach of robustness analysis is to use response surface to study sensitivity of input scatter to output values to be evaluated. However, discussing direct influence of input scatter to output scatter is not realistic, as the production process is highly non-linear so that a new approach needs to be discussed taking into account scatter propagation path.
This paper describes visualization of scatter mode and propagation during a stamping as the first step of robustness study of production process.

Spring back analysis of a S-shaped profile with production scatter

A S-shaped profile is used for the study on scatter in spring back analysis as shown in Fig. 1 Generated by JSTAMP®. The model consists of dies modeled with a RIGID part, and blank with *MAT_024. The press phase is calculated by explicit solver, and spring back analysis is calculated by implicit solver using *INTERFACE_SPRINGBACK_SEAMLESS.
A quasi Monte Carlo simulation (50 runs) is conducted to study scatter in stamping process using LS-OPT. Thickness, friction, material curve has been varied in a reasonable range as shown in Table 1.

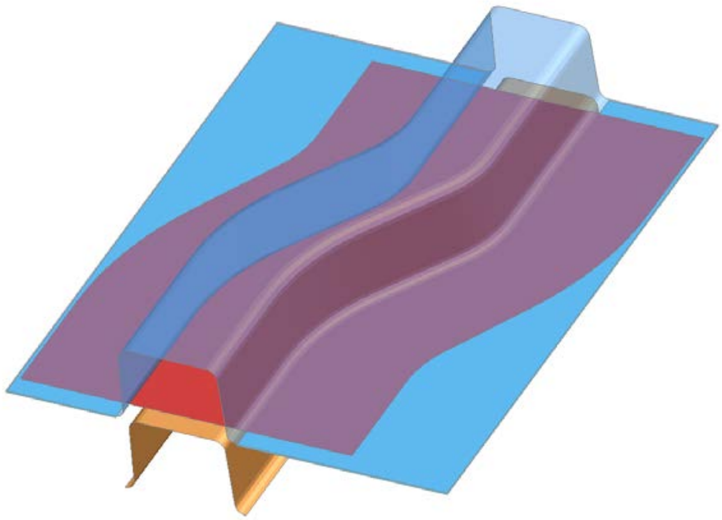


Fig.1: Stamping simulation model for a S-shaped profile.

Parameter	Range	Nominal
Blank thickness	0.776 – 0.808 [mm]	0.8
Yield curve scaling factor of blank	0.95 – 1.05 [-]	1.0
Clamp force scaling factor	0.9 – 1.1 [-]	1.0
Friction coefficient	0.12 – 0.14 [-]	0.13

Table 1: Thickness variation of front side member parts

Scatter visualization of nodal coordinates with DIFFCRASH

As the stamping process is highly non-linear system, evaluating only a few points is not enough to obtain enough insight on the phenomena so that it is essential to take maximum use of animation plot, which contains information on timing, location and propagation path of scatters.

In order to evaluate information from all nodes in all 50 runs, a statistical analysis software DIFFCRASH is introduced. DIFFCRASH is a visualization tool for scatter in simulation which is developed by SIDACT GmbH. BASIC method of DIFFCRASH analyses scatter of nodal coordinate, stress, and strain in each element from multiple FE simulation runs and visualizes the results with contour plot in animation plot.

Fig.2 shows a visualization of scatter in nodal coordinates by DIFFCRASH. The end of the flange is red at the final status of press, which means the scatter at the point is the dominant one, and the trend already appears in the intermediate steps. A red spot on the top in front indicates there is a variation in wrinkle height.

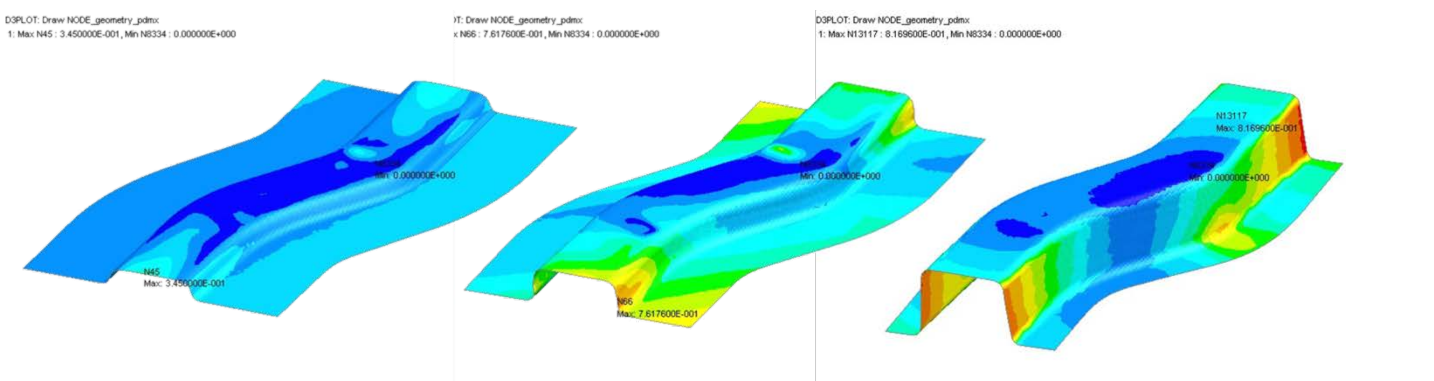
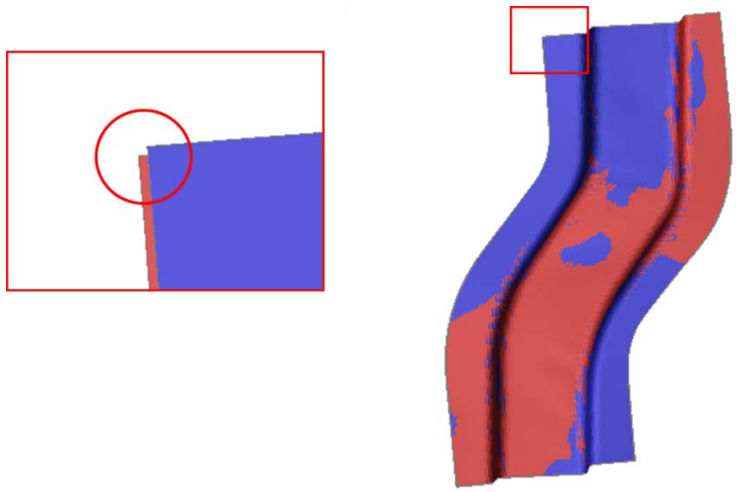
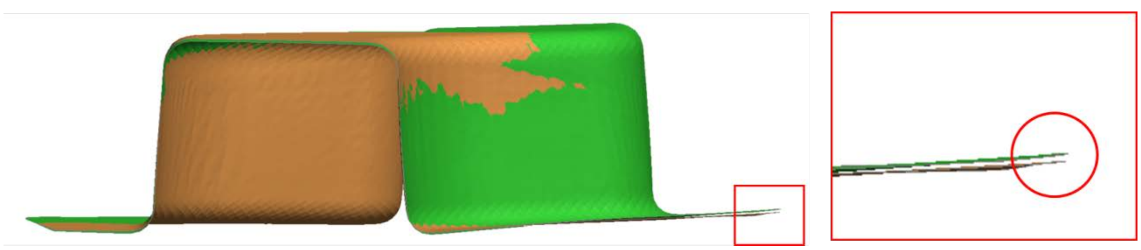


Fig.2: Propagation of scatter in nodal coordinates during stamping process

In order to understand scatter mechanism, PCA (Principal Component Analysis) for the 50 simulation results has been conducted. Fig. 3(a) shows the 1st dominant mode shape at the final status of the spring back analysis. This shows the first mode is a rotational mode around press direction. Fig. 3(b) shows the 2nd dominant mode shape, which shows scatter in spring back in vertical direction. The scatter in 1st mode appears to have occurred during pressing phase. And the 2nd mode appears that it happened during spring back phase, since the nodal coordinate in vertical direction is constrained by the dies. The cause of the 1st mode and the 2nd mode cannot be separated, since the process is highly non-linear. However, the scatter at the flange end can be described as "Rotational mode excited during press phase" + "Vertical mode during spring back phase".



(a) 1st dominant mode (rotational) at an end of a flange



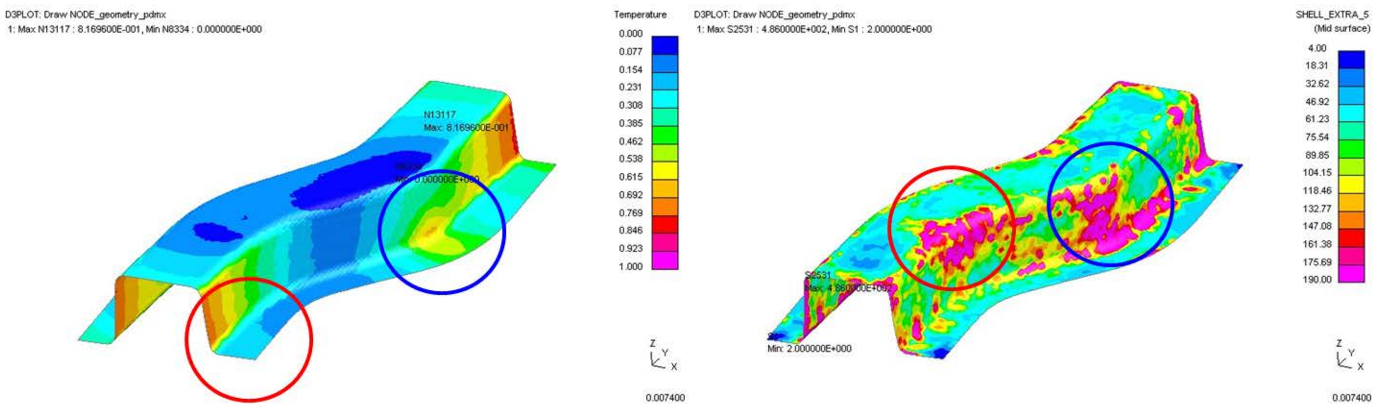
(b) 1st dominant mode (rotational) at an end of a flange

Fig.3: Decomposition of scatter in modal space and contribution level of the 1st and 2nd modes

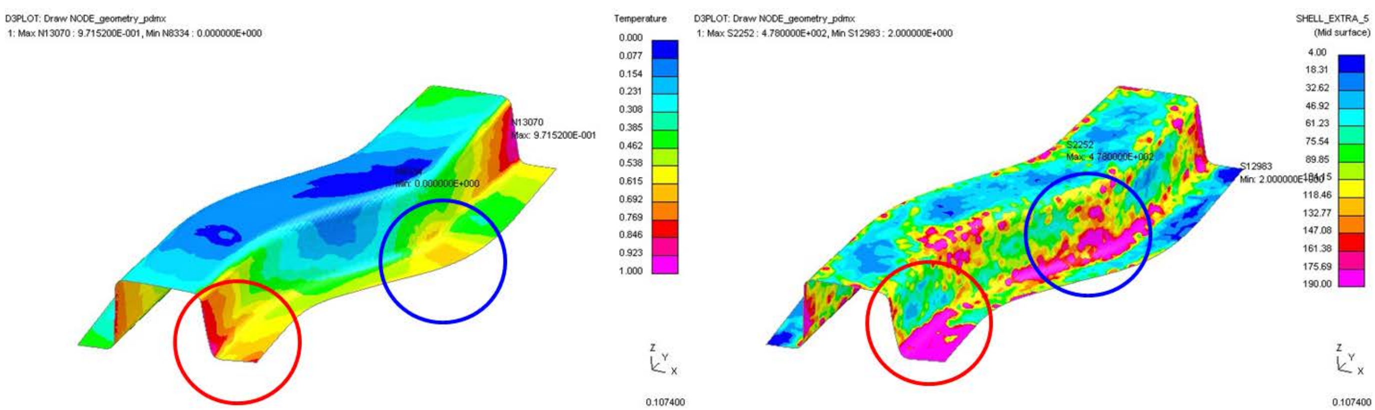
Visualization of scatter propagation path in spring back phase

The driving factor of the 1st mode during press phase is the interaction between the blank and dies including friction, and the driving factor of the scatter during spring back phase is the residual stress contained in the blank. Fig. 4 shows the scatter in the residual stress in the blank during spring back phase.

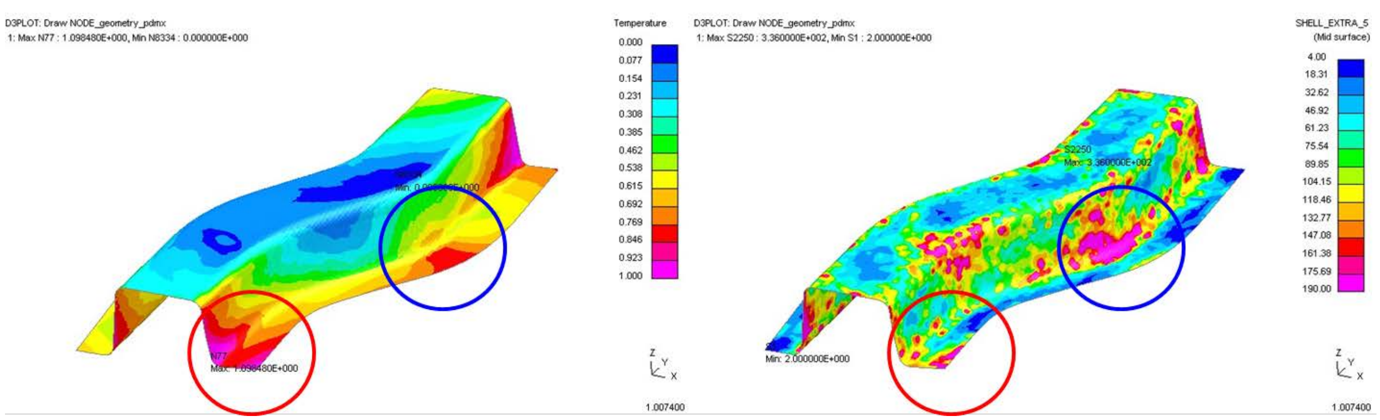
At the final status of the press phase, scatter in nodal coordinate is not significant, but residual stress level is high around the corner area on the top and wall area. During spring back, residual stress in elements are released as constraint from dies are removed, and they are transformed to scatter in nodal coordinate and stress in the next elements. The scatter in stress moves toward the free edge on the flange until it comes to a complete equilibrium. From this analysis, the possible source of scatter in spring back is located. Further study needs to be made for suppressing scatter in residual stress at the final status of press phase.



Final status of the press phase (left: scatter in nodal coordinate, right: scatter in stress)



Intermediate status in the spring back phase (left: scatter in nodal coordinate, right: scatter in stress)



Final status of the spring back phase (left: scatter in nodal coordinate, right: scatter in stress)

Fig.4: Scatter propagation of nodal coordinate (left) and residual stress (right)

Conclusion

In this study, scatter of spring back during stamping process is analyzed by using a statistical approach visualizing scatter path. Important questions for solve engineering problems, "where, when, and what" are given by DIFFCRASH. Embedded scatter information during manufacturing process helps engineers to understand the mechanism of robustness issues. Once mechanism of scatter initiation and propagation is fully understood by asking "why and how" it happens, process can be improved for more robust production process, and it leads to more robust product.

Acknowledgment

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References

[1] M. Okamura, Improvement of Response Surface Quality for Full Car Frontal Crash Simulations by suppressing Bifurcation using Statistical Approach, 11th European LS-DYNA® Conference, 2017