역해석을 이용한 차체 부재의 트리밍라인 최적설계

바오 이동 [1]· 허 훈[#]

Optimum Design of Trimming Line by One-Step Analysis for Auto Body Parts

Y. D. Bao, H. Huh

Abstract

During most of manufacturing processes of auto-body panels, the trimming line should be designed in advance prior to flanging. It is an important task to find a feasible trimming line to obtain a precise final part shape after flanging. This paper proposes a new fast method to find feasible trimming line based on one-step analysis. The basic idea of the one-step analysis is to seek for the nodal positions in the initial blank from the final part, and then the distribution of strain, stress and thickness in the final configuration can be calculated by comparing the nodal position in the initial blank sheet with the one of the final part. The one-step analysis method is able to predict the trimming line before flanging since the desired product shape after flanging can be defined from the final configuration and most of strain paths are simple during the flanging process. Finally, designers can obtain a discrete trimming line from the boundary of the developed meshes after one-step analysis and import it into CAD system in the early design stage. The proposed method has been successfully applied to two basic curve flanging processes demonstrating many advantages.

Key Words: trimming line, optimum design, one-step inverse analysis, flanging

1. Introduction

After drawing of an auto body part, trimming operation is generally performed before flanging. It is essential to find the optimum trimming line to obtain an accurate product shape after flanging. Depending on the auto panel shapes and the flanging processes, there are some basic types of flanges: the straight flange, the stretch and shrink plane flanges, and the stretch and shrink curve flanges. N. M. Wang [1] and C. T. Wang [2] presented two analytical models for stretch and shrink plane flanging. Hu and Li [3] proposed two modified analytical models based on Wang's model. These analytical models can calculate the trimming lines and predict the initial blank contour effectively, but the trimming line of curve flanging can not be obtained by this method.

1. 한국과학기술원 기계공학과
교신저자: 한국과학기술원 기계공학과,
E-mail: hhuh@kaist.ac.kr

Most of auto panel designers are using a section method based CAD tool to design a trimming line. The product section is developed onto the tool section maintaining length automatically by the CAD tool. The end point of a developed product section is defined as one point of the trimming line. The designer has to iterate this process many times along the product outer boundary in order to get a smooth trimming line. The experienced designer has ability to use this method since the result is strongly dependent on the choice of sections.

On the other hand, some researchers have utilized the simulation method to optimize the trimming line. In this method, the incremental FE code such as LS-DYNA™ is used and the optimum trimming line is found by an iterative strategy. It can generate more accurate result than the previous one since this method can consider the deformation mechanism and contact process. However, due to limitation of time and lack of tool information, it is difficult to use this simulation method in the early design stage.

In this paper, we first recall the main assumptions and formulation of one-step analysis. Then the one-step analysis considering the curved binder is investigated. The trimming line is directly given from free edges of the initial configuration. Two examples of curve flanging are considered as the final configurations. The one-step analysis considering a curved binder is used to predict the trimming lines. Then we generate the initial blank from the trimming line for the flanging process. Finally, we utilize LS-DYNA™ to validate the accuracy of the flange height. Results are compared with that from a section method.

2. Optimum design of trimming line

One-step analysis has ability to predict the trimming line since most of strain paths are simple during the flanging process and desired final configuration after flanging can be easily determined from the product shape. One-step analysis can predict the initial configuration on the curved binder surface and extract discrete trimming line from the outer edge of the initial meshes. Then this trimming line is imported into CAD system. Because the input data only need the final part shape and tool mesh, which can be prepared easily before flanging, this method can be integrated into the early design.

2.1 Finite element formulation of one-step analysis

The one-step analysis for sheet metal forming analysis exploits the knowledge of the final work piece shape: starting with the finite element mesh system on the final part, we look for the nodal positions in the initial flat blank. [4~7] Two main assumptions are adopted: one is the proportional loading assumption which avoids the incremental integration of plasticity (deformation theory of plasticity); and the second assumption allows using simplified pressure-friction forces instead of the contact conditions between tools and formed sheets. These assumptions lead to a total or direct method independent of the deformation history.

In the one-step analysis, the principle of virtual work is established on the known final workpiece with respect to this itself as a reference that gives a very simple expression of PVW,

$$W = \sum_{i=1}^{n} \left(\int_{V^e} \langle \varepsilon^* \rangle \{\sigma\} dV - \int_{V^e} \langle u^* \rangle \{f\} dV \right) = 0 \quad (1)$$

Where $\langle \varepsilon^* \rangle$ and $\langle u^* \rangle$ are the virtual strains and virtual displacements, $\{\sigma\}$ are the Cauchy stresses and $\{f\}$ are the external forces such as tool actions and draw-bead restraining forces.

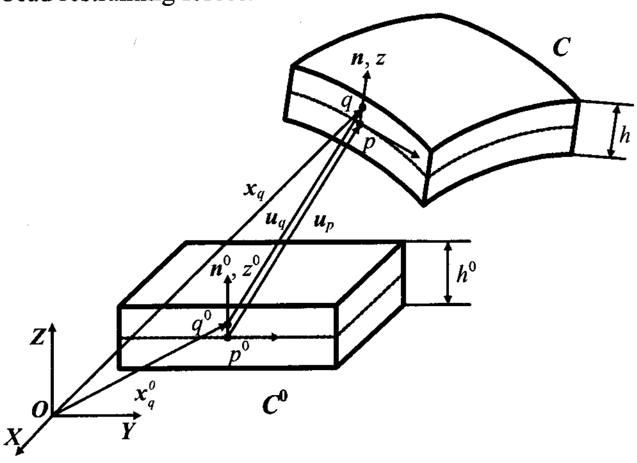


Fig. 1 Shell geometry and kinematics

Using a generalized Kirchhoff assumption, the initial and final position vectors of a material point q can be expressed with respect to the point p on the mid-surface of C as shown in Fig.1. The inverse Cauchy-Green left tensor can be obtained by

$$\langle dx_q^0\rangle\{dx_q^0\} = \langle dx_q\rangle[B]^{-1}\{dx_q\} \quad (2)$$

The eigenvalue calculation of $[B]^{-1}$ gives two principal plane stretches λ^1, λ^2 and their direction transformation matrix $[M]$. Then, the thickness stretch λ^3 is calculated by the incompressibility assumption. Finally, the logarithmic strains are obtained as:

$$[\varepsilon] = [M]\begin{bmatrix} \ln\lambda_1 & 0 & 0 \\ 0 & \ln\lambda_2 & 0 \\ 0 & 0 & \ln\lambda_3 \end{bmatrix}[M]^T \quad (3)$$

In the one-step analysis, only the initial C^0 and the final configuration C are compared. Therefore, the elastic-plastic deformation is assumed to be independent on the loading path and a total constitutive law is obtained,

$$\begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{bmatrix} = \frac{2\bar{\sigma}(2+\bar{r})}{3\bar{\varepsilon}(1+2\bar{r})}\begin{bmatrix} 1+\bar{r} & \bar{r} & 0 \\ \bar{r} & 1+\bar{r} & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{xy} \end{bmatrix} \quad (4)$$

Where $\bar{\varepsilon}$ and $\bar{\sigma}$ are the total equivalent strain and equivalent stress. The mean planar isotropic coefficient $\bar{r}$ is obtained from the three anisotropic coefficients with the relation, $\bar{r} = (r_0 + 2r_{45} + r_{90})/4$.

Since the one-step analysis cannot deal with contact problems depending on the loading history, the tool actions (punch, die and draw-bead) are simply represented by some external forces at the final configuration. The consideration of the tool actions will give the external force vector, leading to the following non-linear equilibrium system.

$$\{R(U,V)\} = \sum_e (\{F_{ext}^e\} - \{F_{\text{int}}^e\}) = 0 \quad (5)$$

2.2 One-step analysis considering curved binder

The binder design is an important task during the addendum design process. The binder shape is usually the curve surface. The quality of product is effected directly by the rationality of the binder shape. The one-step analysis considering the curved binder has two steps. Firstly, the final workpiece nodes move back onto the curved binder surface which is defined in advance. In the first step, the Z coordinate of each node on the intermediate configuration is not an independent variable and is obtained from the X and Y coordinates by a robust nodal projection algorithm.[8] For the speedup, this nodal projection algorithm is divided two processes of global search and local search. The tool node which is nearest to a projection point is found and the node adjacent elements are considered as the local search region which has possibility to contain this projection point. Then the exact projection element is determined by the arc length method during the local search process. However, the global search strategy will fail if the tool mesh has very severe aspect ratios and different sizes. In this case, the local search region needs to be expanded until the exact projection element is determined. Then the intermediate configuration in the curved binder surface develops onto a flat blank. The second step from the flat blank to a curved binder is elastic deformation since the curvature radius of the binder is large enough.

2.3 Extraction of trimming line

The trimming line is extracted from the initial mesh by free edge identification and connection after one-step analysis. For every element side, there are two edge types: common edge and free edge. The common edge as the inner edge has two adjacent elements; on the other hand, the free edge as the outer boundary has only one adjacent element. All free edges can be identified easily using this characteristic. Finally, we generate a trimming line by chaining free edges and export it to CAD system.

3. Numerical results

Two basic curve flanging are simulated by one-step analysis and their trimming lines are predicted synchronously. Then, we compare the trimming line from one-step analysis with that from a traditional section method. Finally, the accuracy of these trimming lines is validated by LS-DYNA™ software. The mechanical properties of a material and test conditions are as follow: the initial sheet thickness=1.0mm; the average Lankford value R_{avg}=1.6; the friction coefficient=0.15; and the flow stress curve of $\bar{\sigma} = 549.03(0.0013+\bar{\varepsilon})^{0.22}$ (MPa).

3.1 Curve flanging

The geometry model of two basic curve flanging is shown in Fig. 2. The sizes of two models are: L =

400mm, $b = 20$mm, $R_1 = 720$mm, $R_2 = 50$mm, $r = 3$mm.

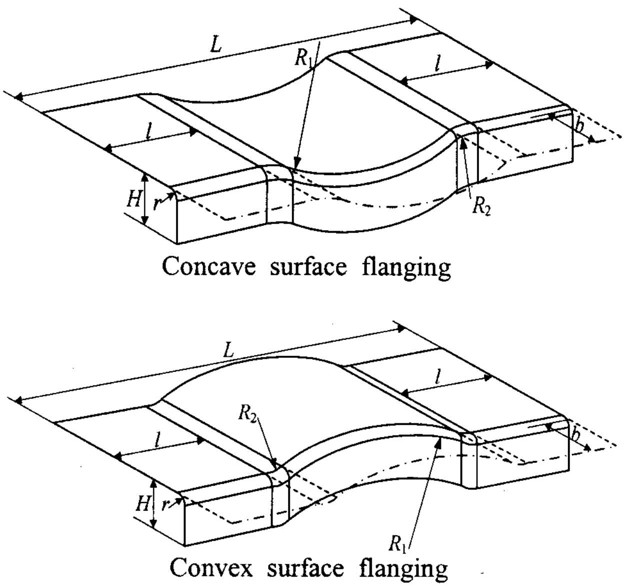


Fig. 2 The geometric models of two basic curve flanging

The geometry of concave surface flanging discretized with 4140 elements and 4309 nodes is shown in Fig. 3 (a) and the geometry of convex surface flanging discretized with 4209 elements and 4380 nodes is shown in Fig. 3 (b). The binder surfaces of two curve flanging are also discretized into an element mesh system respectively as shown in Fig. 3.

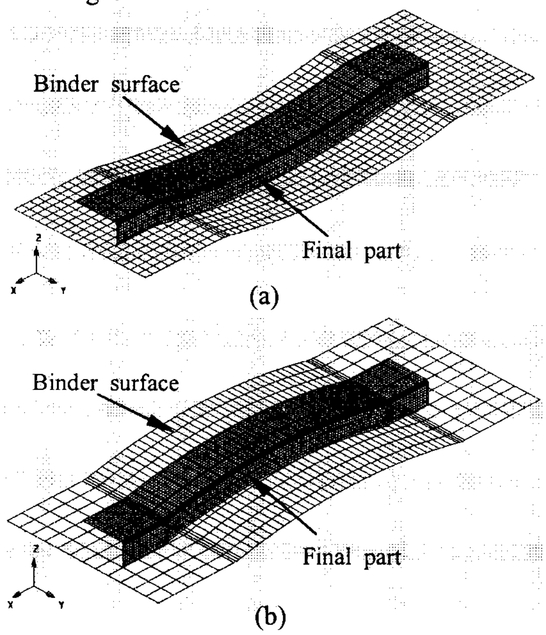


Fig. 3 FEM model of curve flanging

Using one-step analysis considering the curved binder, the trimming lines of two basic curve flanging are predicted directly. In Fig. 4, trimming lines from one-step analysis are compared with that from a section method. Trimming lines from two types of flanging by a section method are both a straight line since it cannot consider any mechanical deformation. However, trimming lines by one-step analysis are very different from by a section method since one-step analysis considers the flanging deformation. The concave surface flanging induces stretch deformation and the convex surface flanging induces shrink deformation during the flanging process. The trimming line of stretch curve flanging should have positive offset for stretch while the trimming line of shrink curve flanging should has negative offset for shrink as shown in Fig. 4.

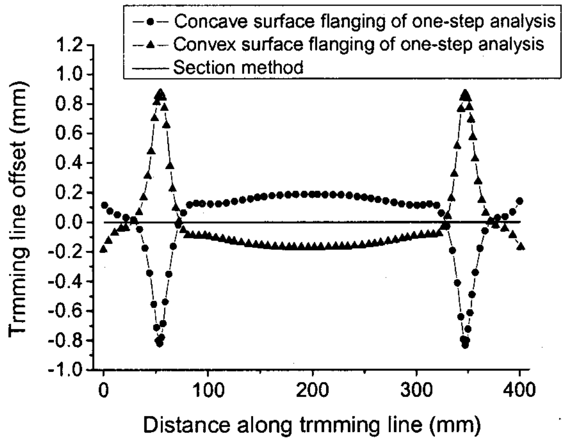


Fig. 4 Comparison of trimming line offset

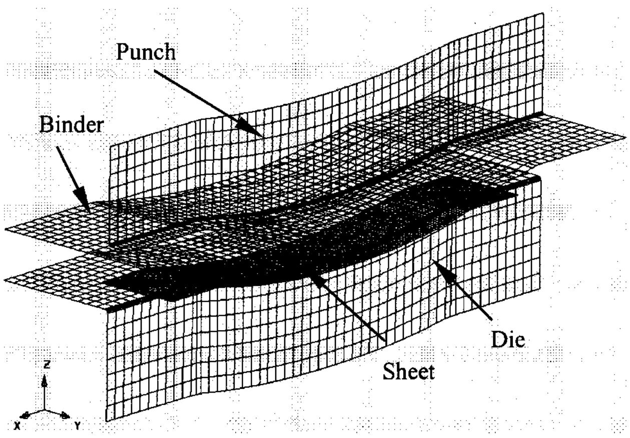


Fig. 5(a) FEM models of flanging process of concave surface flanging

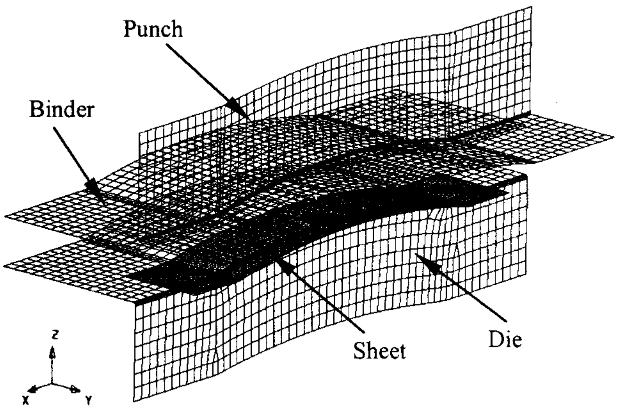
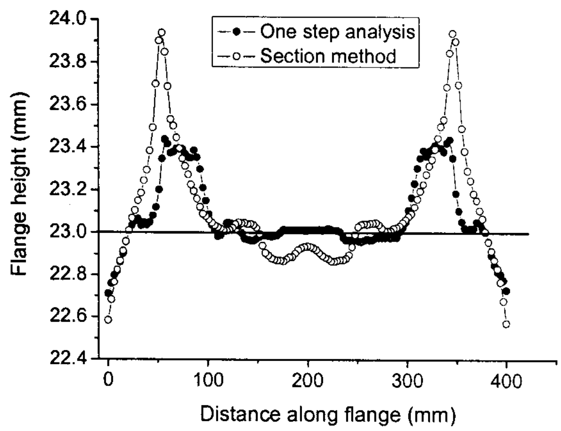
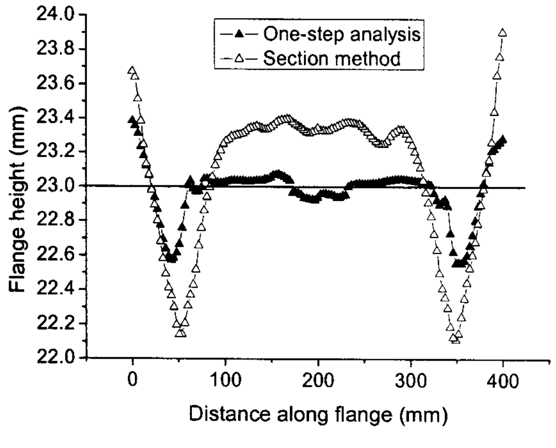


Fig. 5(b) FEM models of flanging process of convex surface flanging



Concave surface flanging



Convex surface flanging

Fig. 6 Comparison of flange height deviation

We generated the initial blank for the flanging process with different trimming lines from one-step analysis and a section method respectively. Then, the flanging process is simulated by the LS-DYNA^{TM} software with the FEM models of the flanging process as shown in Fig. 5(a) and Fig. 5(b). Finally, the flange height along the flange can be obtained from the final state shape. The results are compared with the target flange height.

Figure 6 shows the comparison in the flange height deviation from the target flange height between the one-step analysis and a section method after the flanging process. The flange height from one-step analysis deviates less from the target value remarkably than that from a section method.

4. Conclusion

A new approach of a trimming line optimum design is proposed and outlined. A very efficient procedure for optimum design of a trimming line has been obtained by coupling it with one-step analysis. By using one-step analysis, the initial mesh shape is obtained from the final product mesh shape after flanging. A trimming line is exacted from the free edge from the mesh system developed. The comparison with the result by the LS-DYNA software demonstrates that the proposed method predicts the trimming line more directly and accurately than a traditional section method. It is expected that the one-step analysis can be implemented into the trimming die design in the early stage for a quick and effective design process.

5. Acknowledgement

This work was funded by the Brain Korea 21 (BK21) project from the Ministry of Education and this support is gratefully acknowledged.

References

[1] Wang, N. M. etc., 1974, An analytical and experimental study of stretch flanging. Int. J. Mech. Sci., pp. 135-143.

[2] Wang, C. T. etc, 1974, Wrinkling criterion for an

anisotropic sheet with compound curvatures in sheet forming. Int. J. Mech. Sci., pp. 945-960.

[3] Hu, P., Li, D. Y., Li, Y. X., 2003, Analytical models of stretch and shrink flanging. Int. J. Mach. Tools & Manufacture. 43, pp1367-1373.

[4] Lee, C. H., Huh, H., 1998, Blank design and strain estimates for sheet metal forming processes by a finite element inverse approach with initial guess of linear deformation. Journal of materials processing technology. 82, pp. 145-155.

[5] Kim, S. H., Kim, S. H., Huh, H., 2001, Finite element inverse analysis for the design of intermediate dies in multi-stage deep-drawing processes with large aspect ratio. Journal of materials processing technology. 113, pp. 779-785.

[6] Batoz, J. L., Guo, Y. Q., Mercier, F., 1998, The inverse approach with simple triangular shell elements for large strain predictions of sheet metal forming parts. Engineering Computations. 15(7), pp.864-892.

[7] Guo, Y. Q., Batoz, J. L., Naceur, H., Bouabdallah, S., 2000, Recent developments on the analysis and optimum design of sheet metal forming parts using the simplified inverse approach. Computers and Structures. 78, pp.133-148.

[8] Bao, Y. D., Na, J.X., Hu, P., 2003, Tool Auto-position Algorithm in Sheet Metal Forming Simulation, Journal of Jilin University (Engineering and Technology Edition). 33(Suppl.), pp.169-172.