Optimization of trimming line in sheet metal forming processes by FEM simulation

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ABSTRACT: Due to the complex of geometry and forming processes of the sheet metal part, it is difficulty to determinate trimming line of part before bending or flanging process. The optimization of trimming line based on a multi-step FEM simulation is an effective method. In this paper, a procedure of optimizing the trimming line of an auto body panel by software AutoForm™ has been introduced. With the optimum trimming line, the blank material can be saved and the part can be formed more successfully.

Keywords: Optimization Trimming line Sheet metal forming FEM

Introduction

Trimming is an important step of forming of sheet metal with high precision. Proper trimming process can lead to cost saving in tool construction and material, and promote product precision. To get the blank outline for near-net-shape manufacturing, the sheet boundary should get the desired geometry at the end of the forming steps following the trimming operation. It is difficult to design the profile and trimming line before flanging process, because the unfolding calculation of sheet metal parts is very complicated. The numerical simulations for some separate forming processes such as deep drawing, bending forming and flanging have developed over last two decades. But, the simulations for some progressive multi-step forming processes, including trimming, have not fully developed in past some years. Compared to other processes' simulation, the trimming process simulation involves stress release, element remove or modification, and boundary conditions change etc. For finding a desired trimming line, many incremental or one-step simulations will run. The combine of optimization program and FEM simulation can get the best and proper trimming line.

The traditional method of using a CAD system to unfold a formed sheet part is still very costly and low accuracy, and the unfolding is based on geometry calculation, not on mechanics analysis. In many common CAD softwares, the unfolding calculation is only used for bending process of sheet metal with simple and regular shape. But for some parts with complex shapes and drawing and flanging processes, for example, forming of car body panels, it is difficult for common CAD software to obtain unfolding geometries and shapes.

In general, a trimming process is performed after drawing or bending and before flanging process. A multi-step process simulation will be taken to determine trimming line. Traditionally, before the next step is simulated, the tools are manually removed, and the formed part is prepared for the next process step. This procedure cannot be used optimization for trimming line. For carrying out an optimization program to determine the optimal tool geometry and stamping process, the process steps should be continued and inherited automatically.

So far, some researchers have developed methods to design the optimal blank outline, which include the geometric mapping method [1-2], the trial-and-error method based on the FE method [3-5], the inverse method [6-8], and sensitivity analysis method [9-10]. But little research on optimization of trimming line has been published.

In this paper, an optimal trimming line of a sheet metal part is determined by FEM simulation. The multiple incremental simulations have interactively run. The objective is, at the end of the flanging process step, to optimize the trimming line such that the part boundary is of the desired shape and dimensions.

The forming process simulation is used the finite element method, which is based on the incremental deformation theory and elastic-plastic material modeling. The forming analysis and optimization are carried out using commercial software AutoForm™, which adopts a novel static-implicit algorithm with lower time cost and higher calculation accuracy.

Processing simulation and optimization of trimming line

Blank outline and trimming line definition need to be made in the following typical cases:

1) Calculation of the customized blank sheet for crash forming parts

2) Calculation of the customized blank sheet for a predefined target boundary of a drawing part

3)Calculation of the final cut contour in areas in which additional forming steps follow (e.g. second forming, bending operation, flanging operation)

The whole deformation process has to be analyzed to determine the trimming line when using the finite element method. The forming process simulations need to run several times to obtain the ideal trimming line. Pre-condition for the calculation of the cut contour is simulations for all necessary forming and cutting operations. Basing on this simulation you may define parameters for the calculation of the blank outline and the cut contour. The parameters for the calculation of a trimming line are the target boundary of the part and the forming process after which the target boundary has to be reached. Subsequently, the trimming line of part is modified, and the deformation process is analyzed again by FEM simulation until forming part reaches a specified allowance at every node. Fig. 1 shows the flow chart of the optimal blank and trimming line design. The whole calculation and optimization courses were carried out automatically without the user′s interventions.

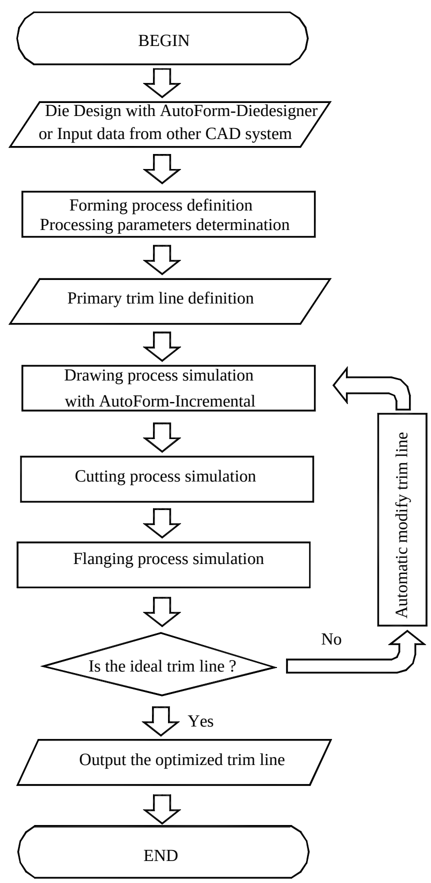


Fig.1 Flow chart of trimming line optimum by FEM

For the calculation of a cut contour, you need the following input:

- Cut contour to be optimized
- Target boundary for the part
- Forming process after which the target boundary has been reached

In the Fig. 2, *P¢¢* represents a node on initial defined trimming line before deformation, and *P¢* represents a node of the after final deformation. The node P is on the target boundary, and ***d*** is deviation between nodes on the final outline and target boundary, which is a key factor to influence iteration times and calculation accuracy.

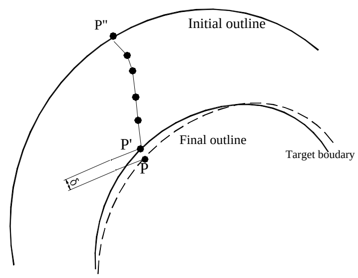


Fig. 2 Nodes move on trimming line in the optimization

There are three key steps in the simulation of the trimming. First, some unused elements should be removed from the meshes. Next, non equilibrated forces are calculated based on the element's stress field for all nodes on the trimming line. Finally, an additional force boundary condition is imposed on each node of the trimming line, and calculations are continued until all nodal forces on the trimming line vanish.

The accuracy of the calculation of the blank outline and the cut contour depends on the chordal deviation of the FEM model for the tools and the part.

Examples

Fig.3 shows a car body panel with a flange. In the forming of the part, gravity, closing, drawing, flanging processes are necessary. The properties of blank material are showed in Table 1. The initial thickness of blank is 0.8mm.

Fig.3 A car body panel

Table 1 Material property of blank

Property	Value
Young's modulues, *E*, (MPa)	2×10^5
Poisson's ratio, *n*	0.3
R-value	R_0 1.70 R_{45} 1.20 R_{90} 1.69
Stress-strain relation, *s* (MPa)	$450\varepsilon^{0.156}$
Coulomb's coefficient of friction, *m*	0.15

The FEM models of tools and blank are showed in Fig.5. The final forming step is flanging, the trimming line need to determinate before this step. The initial blank and the target contour outline have been defined by empirical design (Fig.4). With the given initial blank outline and trimming line, then deformation process has been analyzed until forming finish.

The final blank outline was obtained by 5 iterations (Fig. 4 Hidden line), and it can be export by IGES format.

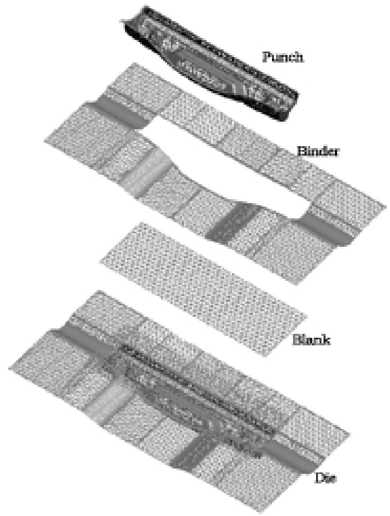
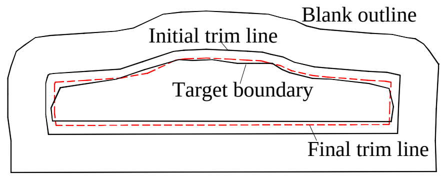
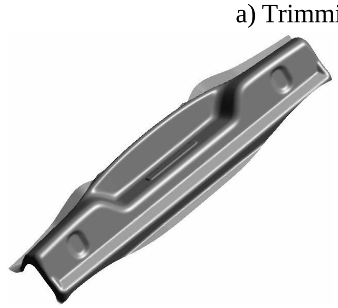


Fig.4 FEM models of tools and blank for simulation



a) Trimming line change



b) Before trimming c) After trimming

Fig.5 Blank outline, target boundary and part after of the calculation of the cut contour

Conclusions

A optimization of trimming line has been applied to the forming of complex auto body panel. The modification of trimming line is based on FEM simulations of all forming steps. The trimming line has been modified to save materials and simplify forming process. Through the investigation, the AutoForm-Trim is effective to determinate blank outline and trimming line.

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References

[1] R. Sowerby, J.L. Duncan, E. Chu, The modeling of sheet metal stampings, Int. J. Mech. Sci. 28 (7)

(1986) 415-430.

[2] G.N. Blount, B.V. Fischer, Computerized blank shape prediction for sheet metal components having doubly curved surfaces, Int. J. Prod. Res. 33 (4) (1995) 993-1005.

[3] C.H. Toh, S. Kobayashi, Deformation analysis and blank design in square cup drawing, Int. J. Mech. Sci. 25 (1) (1985) 15-32.

[4] N. Kim, S. Kobayashi, Blank design in rectangular cup drawing by an approximate method, Int. J. Mach. Tools Des. Res. 26 (2) (1986)125-135.

[5] Y.Q. Guo, J.L. Batoz, J.M. Detraux, P. Duroux, Finite element procedures for strain estimations of sheet metal forming parts, Int. J. Numer. Meth. Eng. 30 (1990) 1385-1401.

[6] H. Iseki, R. Sowerby, Determination of the optimal blank shape when deep drawing nonaxisymmetric cups using a .nite element method,JSME Int. J. Ser. A 38 (4) (1995) 473-479.

[7] O. Barlat, J.L. Batoz, Y.Q. Guo, F. Mercier, H. Naceur, C. Knopf-Lenoir, Optimum blank design of blank contours using the inverse approach and a mathematical programming technique, in: Proceedings of the NUMISHEET'96, 1996, pp. 178-185.

[8] C.H. Lee, H. Huh, Blank design and strain prediction of automobile stamping parts by an inverse .nite element approach, J. Mater.Process. Technol.63 (1997) 645-650.

[9] Hyunbo Shim, Kichan Son, Kwanghee Kim. Optimum blank shape design by sensitivity analysis. J. Mater.Process. Technol.104 (2000) 191-199.

[10] Hyunbo Shim. Determination of optimal shapes for the stampings of arbitrary shaps. J. Mater.Process. Technol.121 (2002) 116-122.