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Optimum Blank Design Using Modified Sensitivity Approach

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Abstract: A modified sensitivity analysis has been applied to an elastic-plastic finite element analysis 3D blank design in sheet metal forming. In recent literature, the sensitivity method has successfully been applied to several arbitrary shapes. However, in the present paper the sensitivity coefficients are not considered constant during the analysis. The presented approach computes the new coefficients from the two last iterations. This method can produce an initial blank boundary shape that has any arbitrary flange shape. A cup with uniform flange has been studied in detail and results show a faster solution convergence than the published sensitivity method. Experimental tests were conducted to compare with the numerical simulations. The optimum blank shape obtained from the numerical simulations was used during the experimental trials. The results of experimental tests for both square blank and optimum blank were presented.

Keyword: sheet metal forming; finite element method; optimal blank; modified sensitivity analysis.

1 Introduction

The numerical simulations of the stamping process are used extensively for the analysis and design of industrial parts to avoid long and expensive experimental try-out procedures [Gelin and Picart (1999), Mori (2001), Makinouchi et al. (1993)]. Together with non-Linearity of materials, the other important factors such as the unsteady nature of the process, large elasto-plastic involved, and the complexity of contact and frictional effects make the study of stamping process so complicated. Sheet metal analysis justifies the use of sophisticated numerically algorithm and usually leads to large scale computer requirements [Tae et al. (2001)].

Optimal blank design technology is required for net-shape cold forming using thin sheet-metals. The net-shape means that the trimming process is eliminated completely in the forming process. Therefore the optimal blank is referred to an initial blank shape to produce a desired shape which includes uniform flange around the

part. The design of the initial blanks has used various methods such as the slip-line method [Karma (1989)], the geometric mapping [Sowerby et al. (1986), Blount and Fischer (1995)], the trial and error method based on the FE method [Toh and Kobayashi (1985), Kim and Kobayashi (1986)] ,inverse method [Lee and Huh (1997)] which uses FE method for the direct prediction of the blank shapes and the strain distributions in the desired final shape, the backward tracing method [Kim et al. (1998)] which its key concept is to trace backward from final desirable configuration to initial blank shape and intermediate deformed shapes.

In this study a modification for initial blank design in sheet forming has been developed and proven in its effectiveness by apply it to square cup stamping process. In the blank design of square cup stamping, the modified sensitivity program can produce a net-shape cup with straight edges with lower iterations.

Finally the deformation with optimal blank is analyzed and its effects on thickness change (thinning) distribution and punch force are investigated.

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2 Basis for the finite element method

The variational formulation approach is based on one of two variatonal principles. It requires that among admissible velocities, ui, that satisfy the conditions of compatibility and incompressibility, as well as the velocity boundary conditions, the actual solution gives the following functional a stationary value:

$$\Pi = \int_V \overline{\sigma}\dot{\overline{\varepsilon}}dv - \int_{SF} F_i u_i ds \tag{1}$$

Where $\overline{\sigma}$is the effective stress:

$$\overline{\sigma}.45 = .45.45 \left(\sqrt{3/2}\left(\sigma'_{ij}\sigma'_{ij}\right)^{1/2}\right) \tag{2}$$

And$\dot{\overline{\varepsilon}}$is the effective strain rate:

$$\dot{\overline{\varepsilon}}.45 = .45.45 \left(\sqrt{2/3}\left(\dot{\varepsilon}_{ij}\dot{\varepsilon}_{ij}\right)^{1/2}\right) \tag{3}$$

In equation 1, F_i represents surface traction, u_i are velocity components, σ'_{ij} is the deviatoric stress tensor and $\dot{\varepsilon}_{ij}$ is the strain rate tensor component.

In sheet metal forming, under the plane stress conditions the Lagrange multiplier, λ, is not necessary [Kobayashi and Altan (1989)] so the variational formulation becomes:

$$\delta\Pi = \int_V \overline{\sigma}\delta\dot{\overline{\varepsilon}}dv - \int_{SF} F_i \delta u_i ds = 0 \tag{4}$$

3 Theoretical background of the sensitivity method

During blank deformation in the deep drawing process, boundary nodes move along the nonlinear deformation path. Therefore the final moving direction is different from the initial direction. The desired shape after forming is obtained when every boundary nodes coincide with target contour at the end of the process. It must be noted that the target shape is a box with a 144*144 mm^2 square flange. In order to make nodes lie on the target contour, the initial position of the nodes should be changed, according to the amount of shape error [Shim and Son (2001)].

Consider X represent a position vector of a material point located at the boundary of an initial

Table 1: ST12 material property

General property:
$\rho = 7800.45.45Kg/m^2.45.45.45.45.45$ $(Density)$
Mechanical properties:
$E = 208.45.45GPa.45$ $(Young's.45Modolus)$
$\upsilon = 0.31.45.45.45$ $(poisson's.45ratio)$
$\sigma_y^0 = 140.45MPa.45.45$ $(initial.45yield.45stress)$

blank before deformation and x represent a position vector of the material after final deformation.

With the initial blank defined by X, the deformation process is analyzed by ABAQUS/Explicit. In the first step of optimization, the deformation of a rectangular blank of 0.103 m with, 0.103 m length, and 1mm thickness from ST12 material is simulated. The computational conditions for the simulations are as T.W.Ku [4] et al considered. The friction coefficient is considered equal to 0.12 between blank surface and forming tools. The material property of ST12 sheet material is as shown in table 1. Figure 1 shows the uniaxial tension curve used for plastic behavior definition.

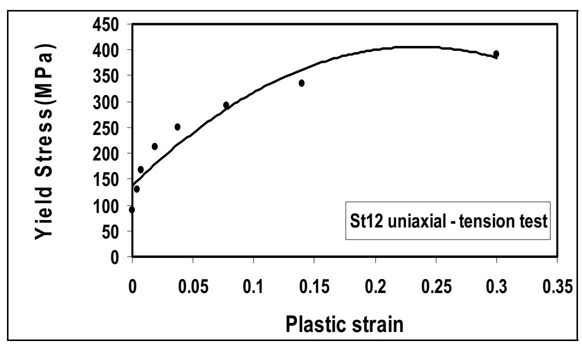


Figure 1: St 12 uniaxial tension curve

The result of first simulation is represented in figure 2. Because of part's symmetrical geometry, $1/4$ of the blank is modeled.

If x doesn't lie on the target contour x_T, as shown in figure3, the position of the material point before deformation X should be modified in order to make the deformed contour coincide with the target. In this method the shape of initial blank can be changed by use of shape sensitivity S.

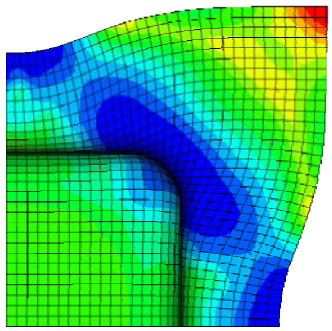


Figure 2: The result of initial square blank deformation

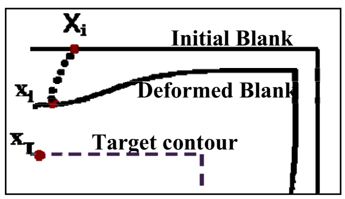


Figure 3: Schematic of blank deformation

The shape sensitivity is derived numerically by considering the original and the offset blank. The offset blank shape (X_δ) determined from the result of FE analysis with the initial blank [13]:

$$X_\delta = X + \delta.N \tag{5}$$

Where N is the unit vector in the moving direction at the first increment and δ is amount of offset. Fig 4 shows the offset blank obtained when δ is taken as 2 mm.

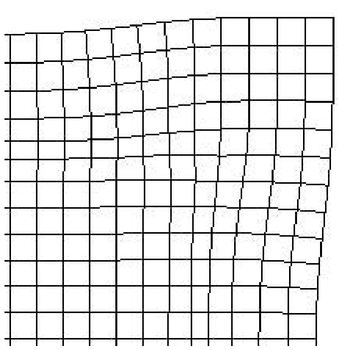


Figure 4: Offset blank

The deformation process is analyzed again to obtain x_δ, the position of boundary nodes after deformation for the offset blank. Then the shape sensitivity for the deformation at each node is defined as:

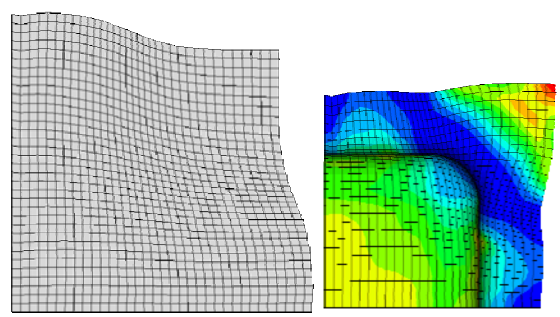
$$S = \frac{|X_\delta - X|}{|x_\delta - x|} \tag{6}$$

Unless x lies on the target contour, then the corresponding initial position should moved by:

$$X^{(i)} = X^{(i-1)} - \varepsilon S.N \tag{7}$$

Where ε is the shape error, defined as the between x_T and x. Superscript (i) means number of iteration.

After the first modification of the blank shape the deformation process is analyzed again and the contour of deformed blank extracted. Figure 5-a,b show the first blank modification and its deformed shape respectively.



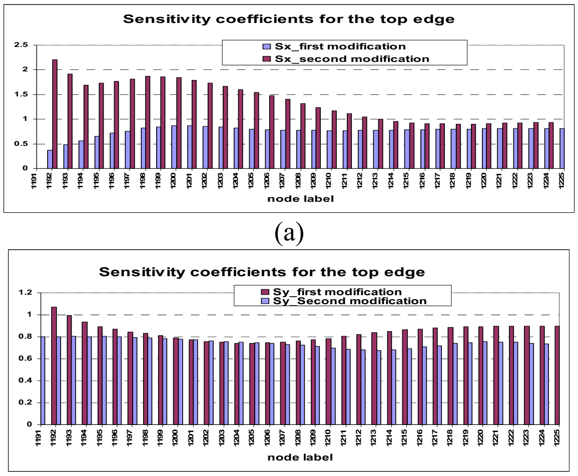
(a) (b)

Figure 5: First blank modification: (a) blank shape; (b) deformed shape

The shape error at boundary nodes is grater than maximum allowable error (1mm in this study), so the blank shape must be modified again. In order to modify the blank for second time, the new sensitivity coefficients are required.

In despite of Shim and Son (2001) research, the sensitivity coefficients have changed in second modification. Variation of sensitivity coefficients for top edge nodes are illustrated in figure 6-a, b.

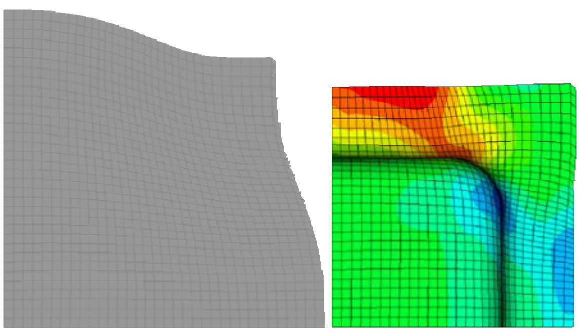
According to the new sensitivity coefficients, blank boundary is modified and its deformation is simulated. Figure 7-a,b represent modified and deformed blank respectively.



(a)

(b)

Figure 6: Variation of sensitivity coefficients: (a) X component (Sx); (b) Y component (Sy)



(a) (b)

Figure 7: Results of second modification: (a) Optimal blank ;(b) deformed blank

4 Results and discussions

Fig. 8 shows the comparison between the flange contours in different steps of optimization. For the optimal blank determined by the second modification, the flange contour after deformation coincides with the target contour.

Shape error distribution in the right edge of the blank is shown in figure 9. In the second modification, shape error values are less than 1mm that is highly acceptable in this study.

The main purpose of using optimum blank is minimizing material-consumption in deep drawing process. However this kind of blank optimization has some effects on forming parameters. In this

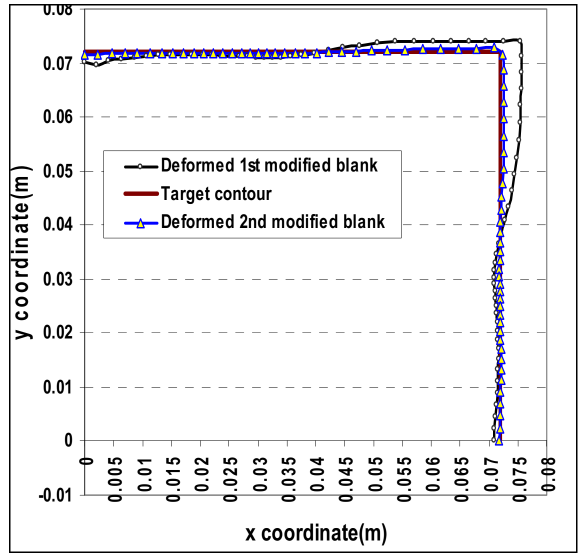


Figure 8: The comparison between deformed contours

article, a variation of two important parameters by using optimum blank are investigated.

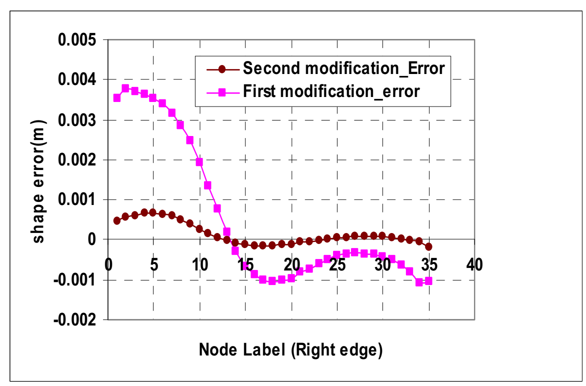


Figure 9: Variation of shape error in the right edge of blank during optimization.

The first parameter is deformation force (The force that punch applies to the sheet metal and deforms it successfully). Figure 10 shows deformation force for two different initial blank (square blank and optimum blank) in box deep drawing.

According to figure 10, maximum deformation force decreases from 96KN to 61KN (almost 35% reduction) by means of optimum blank. This amount of reduction is highly significant for deep drawing process.

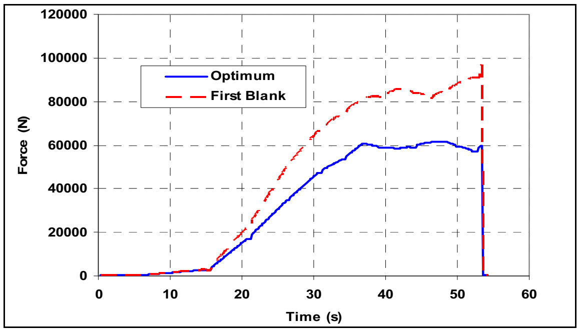


Figure 10: Deformation force for two different initial blank (square blank and optimum blank)

This reduction can be explained by the area of initial blank. The area of optimum blank between die and blank holder is 25% smaller than first square blank. Therefore, the punch force that is required to overcome frictional force has decreased accordingly.

The next parameter is thickness distribution or amount of thinning in deformed box. The values of thinning in two different sections (figure 11-a) are illustrated in figures 11-b, c.

According to the thickness distribution curves, thinning values in optimum blank are decreased, compare to First rectangular blank. The main reason of this reduction can be smaller radial force again. This force is directly related to the material-flow and thickness distribution. High radial force acts like a strict clamping and do not let material to flow in the initial square blank. Figure 12 shows the experimental results of square blank drawing and die set components.

According to the figure 12, earing defect is observed. To reduce the earing defect an optimum blank instead of square blank is used. Figure 13 illustrates the optimum blank shape. The shape of deformed blank after drawing process is presented in figure 13b. It can be seen that the shape of optimum blank which were originally obtained from numerical analysis has significantly reduced the earing defect. However due to differences in material property and frictional contact conditions used in the numerical simulations compared to experiments, the edge of the final product is not fully straight.

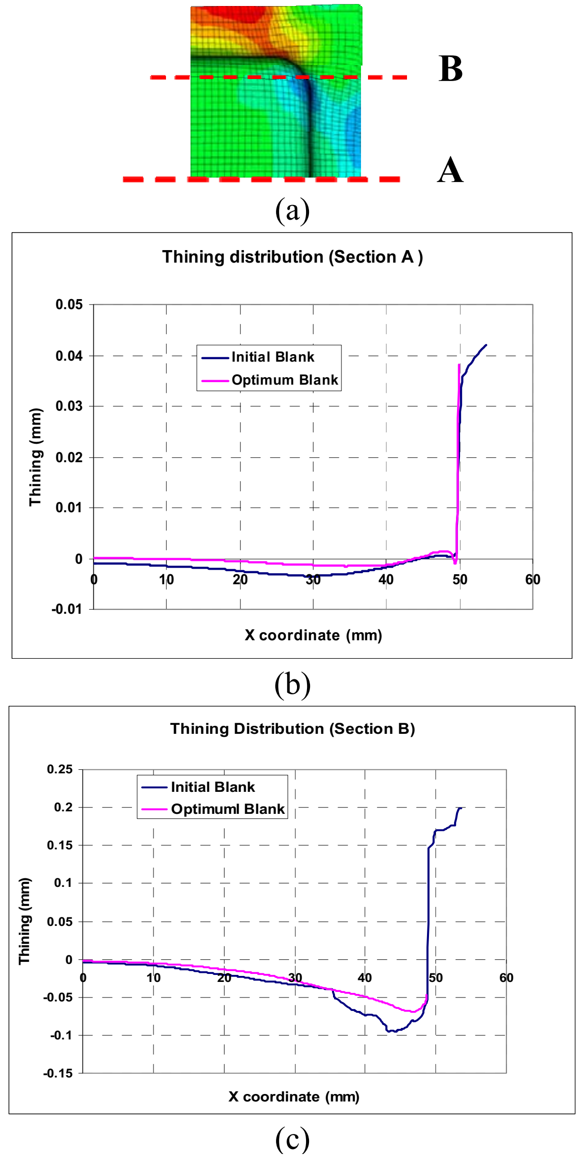


Figure 11: (a) sections a, b; (b) Thinning distribution in section A; (c) Thinning distribution in section B

5 Conclusion

A program of optimal blank design based on modified sensitivity analysis for deep drawing process has been developed. This program computes the components of shape sensitivity (Sx, Sy) for boundary nodes using deformation results. Then it determines the shape error for every boundary nodes and modifies the initial blank shape with the shape sensitivity in order to obtain the final target shape.

Figure 12: (a) Die set components; (b) Drawn blank

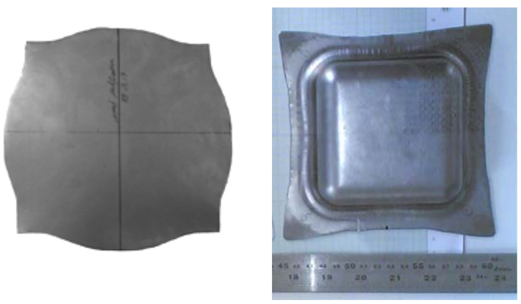


Figure 13: (a) Optimum blank; (b) Drawn optimum blank

Deformation force decreased about 35% using optimum blank. Finally it has shown that optimal blank has changed the thinning distribution in deformed part significantly, the thickness distribution has become more uniform and the failure probability has been reduced.

Experimental tests showed that the shape of optimum blank has significantly reduced the earing defect. However due to differences in material property and frictional contact conditions used in numerical analysis compared to experiments, the edge of the final product is not fully straight.

References

Gelin, J.C.; Picart, P. (1999): in: Proceedings of the Fourth International Conference on Numerical Simulation of 3D Sheet Metal Forming processes, NUMISHEET'99, Besançon, France.

Mori, K. (2001): Simulation of material processing: theory, methods and applications, in: Proceedings of the Seventh International Conference on Numerical Methods in Industrial Forming Processes, NUMIFORM'2001, Toyohashi, Japan.

Makinouchi, A. et al. (1993): in: Proceedings of the Second International Conference on Numerical Simulation of 3D Sheet Forming processes–Verification of Simulation with Experiment, NUMISHEET'93.

Tae Wan Ku; Lim, H.J.; Choi, H.H.; Hwang, S.M.; Kang, B.S. (2001): Implementation of backward tracing scheme of the FEM to blank design in sheet metal forming, *Int. J. Material processing technology*, 111, pp. 90-97.

Karma, M. (1989): Blank development and tooling design for drawn parts using modified slip line field based approach, *J. Eng. Ind, Trans. ASME*, 111 345-350.

Sowerby, R.; Duncan, J.L.; Chu, E. (1986): the modeling of sheet metal stampings, *Int. J. Mech. Sci.*, **28**, pp. 415-430.

Blount, G.N.; Fischer, B.V. (1995): Computerized blank shape prediction for sheet metal components having doubly-curved surfaces, *Int. J. Prod. Res.*, **33**, pp. 993-1005.

Toh, C.H.; Kobayashi, S. (1985): Deformation analysis and blank design in square cup drawing, *Int. J. Mech. Sci.*, **25**, pp. 15–32.

Kim, N., and Kobayashi, S. (1986): Blank design in rectangular cup drawing by an approximate method, *Int. J. Mach. Tool Des. Res.*, **26**, pp. 125-135.

Lee, C.H.; Huh, H. (1997): Blank design and strain prediction of automobile stamping parts by an inverse finite element approach, *J. Mater. Process. Techno.*, **63**, pp. 645-650.

Kim, S.D.; Park, M.H.; Kim, S.J.; Seo, D.G. (1998): Blank design and formability for non-circular deep drawing processes by the finite element method, *J. Mater. Process. Techno.*, **75**, pp. 94-99.

Kobayashi, S.I.; Altan, O.T. (1989): *Metal forming and the finite element method*, Oxford university press.

Shim, H.B.; Son, K.C. (2001): Optimal Blank Design for the Drawings of Arbitrary Shapes by the Sensitivity Method, *Int. J. ASME*, 123, pp.468-475.