**Article ID:** 1003 - 6326(2003)04 - 0839 - 06

# Numerical simulation of two-stage deep drawing of complex-shaped parts ①

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**Abstract:** Choosing inner-door panel of auto as an example, the two-stage deep drawing of complex sheet metal was studied. By using CAD software UG and numerical simulation software DYNAFORM, the characteristic of the CAD modeling of the simple workpiece and the complex sheet metal, finite element modeling and the selection of parameters were analyzed. The effects of three important material parameters such as yield stress, strain hardening exponent and normal anisotropic parameter on the formability of the two-stage deep drawing of inner-door panel of auto were investigated. The results show that the yield stress has large influence on the increase of thickness, while the strain hardening exponent has little effect on the thickness change. Otherwise, larger normal anisotropic parameter can result in a better formability of the sheet.

**Key words:** inner-door panel of auto; complex sheet metal; two-stage deep drawing; numerical simulation
**CLC number:** TG 301 **Document code:** A

## 1 INTRODUCTION

In recent years, with the rapid development of computer software and hardware, and the intersection and combination of computer technology, graphics, mechanics and process engineering, the computer aided engineering(CAE) technology based on numerical simulation has been widely applied in the sheet metal forming field[1, 2]. Nevertheless, until now, the numerical simulation is confined to simulate some basic modes of deformation such as bending, deep drawing, bulging and flanging. For the deformation of complex work-pieces, for example, the auto panel forming, the research work is very limited and is difficult to guide the real processing[3-7].

This paper takes inner-door panel of auto (as shown in Fig. 1) as model to research the two- stage deep drawing of complex sheet metal. In general, the forming of auto panel involves severalstamping processes such as blanking, deep drawing, redrawing, trimming, flanging, and punching. In most cases, deep drawing is a key technology to inner-door panel of auto, which directly affects product quality, material utilization, production efficiency, and manufacturing cost. On the other hand, due to its large drawing depth, the inner-door panel of auto must be formed through two-stage drawing[7-12].

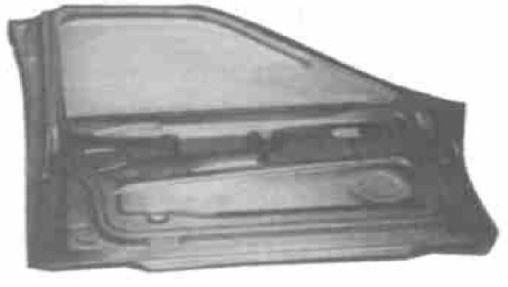

**Fig. 1** Inner door panel of auto

## 2 FORCE CHARACTERISTICS OF INNER-DOOR PANEL OF AUTO

In the forming of inner-door panel of auto, it needs the bulging deformation of sheet center and the bending deformation of circumambient flange uniformly and simultaneously. The deformation along the circumambience of sheet metal varies, i. e. the deformation extent of straight sides is smaller, so the radial tension stress needed is smaller; on the other hand, the deformation extent of curved sides is larger, so the radial tension stress needed is larger. The radial tension stress varies sharply along the sidewall of the whole circumambience. In the area where the drawing deformation is very small, the radial tension stress is too small to lead enough bulging deformation at the center of sheet metal, and under this circumstance, a relatively large tangential compressive stress could induce wrinkling in this area and destroy the deformation condition. So, when the inner-door panel of auto is made, a relatively uniform radial tension

① **Foundation item:** Project(015211009) supported by Science and Technology Development Foundation of Shanghai, China
**Received date:** 2002 - 07 - 08; **Accepted date:** 2002 - 12 - 04
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stress must be produced along the whole circumambience, which could induce enough bulging deformation at the center of sheet metal. Acquiring a relatively uniform radial tension stress is the key to the deformation of inner-door panel of auto.

Just as inner-door panel of auto, its deformation areas are the whole sheet metal in deep drawing. But the stress status, deformation properties and existent problems have great differences in each of areas. According to the deformation characteristics, the whole sheet metal can be divided into different parts:

1) Top of complex surface

This area is that the punch firstly contact with the sheet metal, so it is the primary part being deformed, and in the subsequent deformation process, its main duty is to transmit drawing force. Whether or not this area continues to deform plastically depends on the deformation condition of this area.

2) Suspending area

The suspending area doesn't contact with the punch during the whole deformation process, and cannot get direct effects from the surface of punch. This area realizes the control to deformation of sheet metal by the tensile force produced by the top area of complex surface and the flange area under the blank holder. Because this area is in suspending state, it is likely to induce inner-wrinkling defect; on the other hand, if the tensile force is very large, it is likely to induce the fracture defect. So it is the key deformation area of complex sheet metal.

3) Flange area

The flange area is under the blank holder. Its deformation and deformation properties depend on the shape of workpiece and friction condition. If necessary, controlling the moving condition of this area can make the sheet metal flow into the die and supplement the material needed to deform. This area is confined by the surface of die and the blank holder. Because the area is influenced directly by the mould, the deformation-controlling problem of this area can be solved easily. However, its function is not only to deform itself, but also to affect the deformation of the whole blank. The area determines whether the suspending area can fit the die smoothly or not, so adjusting the deformation condition and friction resistance reasonably will make the stress state and deformation characteristic of the suspending area change. Thereby, setting up the deformation condition of the area properly is the key measure to make the workpiece deform successfully.

From the above we can know, different areas of the blank perform different functions in the whole deformation process, and their load conditions and deformation characteristics are not unanimous. Their interaction is very complicated. Precisely grasping and reasonably controlling these rules are of importance for guiding the deep drawing forming of complex sheet metals. As a matter of fact, as far as the inner-door panel of auto is concerned, the choice of its stamping technology, the decision of designing dies, and measurement of solving the problems existed in the production and so on, are based on the functions of every area in the deforming, the loading characteristics and deformation law, and how to realize the controlling of the deformation.

## 3 RESEARCH IDEA ON TWO-STAGE DEEP DRAWING OF INNER-DOOR PANEL OF AUTO

Like inner-door panel of auto, if adopting the traditional method, e. g. the physical simulation method, to study the complex sheet metal, because the elastoplasticity of sheet metal could not be analyzed accurately according to theory, the technology system and the qualified workpiece could be ensured, but the cost is too expensive. So it is necessary to study complex sheet metal by using numerical simulation methods.

The specific steps of the simulation method are listed as follows.

1) Simplified model of inner-door panel of auto

At first, reverse engineering is used to get the CAD model of the real inner-door panel of auto, and the model is shown in Fig. 2. But according to the simulation analyses, this model is very complicated. The excessive geometric details of the model make the CAD model be much more difficult. When generating finite element mesh, a very dense mesh must be adopted and make the finite element model of inner-door panel of auto be very large. In fact, geometric details have little effect on the deformation of the whole workpiece, in other words, removing these geometric details from the CAD model will have little effect on the accuracy of digital simulation of deformation. From above analyses, based on the geometric characteristic of inner-door panel of auto, we designed the simplified inner-door panel of auto model, as shown in Fig. 3.

2) Building of geometric model of inner-door panel of auto

The CAD models of the mould are constructed in two-stage deep drawing by the CAD software UGII. The CAD models of the dies are shown in Fig. 4 and Fig. 5.

3) Building of FEM model of inner-door panel of auto

The CAD model of IGES format is imported into the numerical simulation software DYNAFORM. Fig. 6 shows the FEM model of the first-step deep drawing. The difference between the FEM models of the second-step deep drawing and the first-step deep drawing is that the blank used in the second-step is

**Fig. 2** Real inner-door CAD model

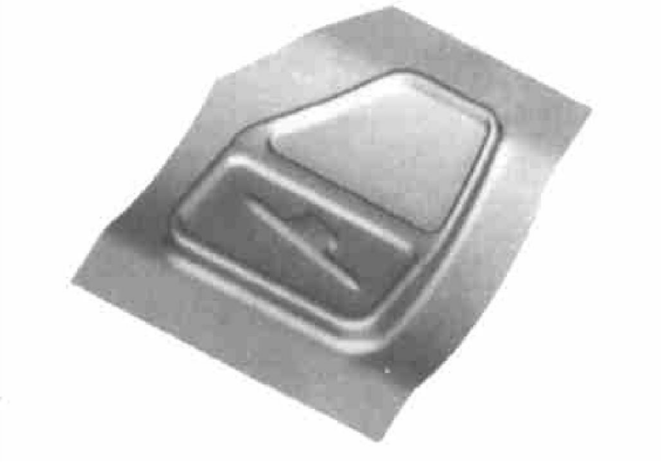

**Fig. 3** Simplified inner-door CAD model

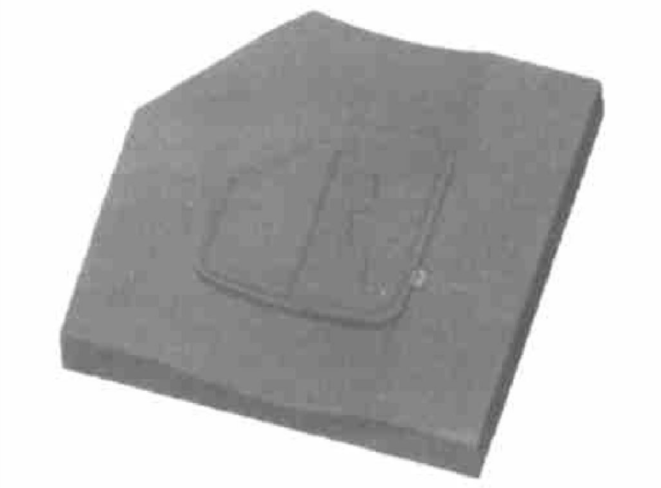

**Fig. 4** First-step drawing CAD model of die

the blank after the first-step deformation. To keep the consistency of the two-steps of deep drawing, in second-step deep drawing, regeneration of mesh and reorder are not needed.

4) Numerical simulation research on inner-door panel of auto

After establishing the FEM model of inner-door panel of auto, a lot of numerical simulation works are

**Fig. 5** Second-step drawing CAD model of die

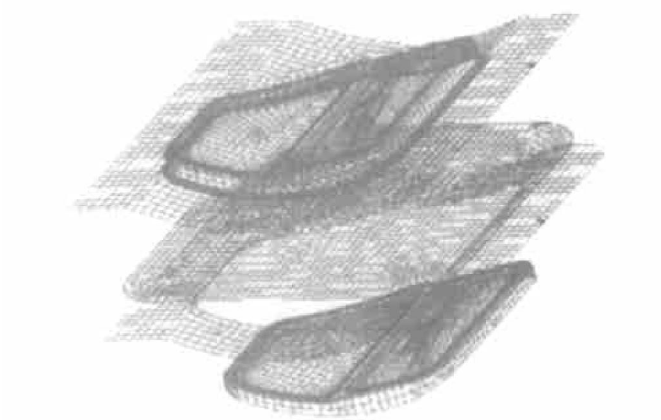

**Fig. 6** FEM model of first-step deep drawing

done. At the beginning of the simulation, due to the unreasonable design parameters and technological parameters, reasonable results could not be achieved. Through adjusting the radius and blank-holder force, at last the die parameters that can lead to a successful two-stage deep drawing are got. Among these parameters, the inner radius of the punch are defined as 3.0 mm, and its outer radius are defined as 2.5 mm. Based on all these parameters in designing the die of physical simulation, a successful deep drawing was finished without any modifications, which clearly proves that numerical simulation is very important in designing complex die. The inner-door panel of auto is shown in Fig. 7 after two-stage deep drawing.

## 4 EXAMPLES OF SIMULATION FORMABILITY OF INNER-DOOR PANEL OF AUTO

This paper utilized numerical simulation to research the effect of three important material parameters on the formability of the two-stage deep drawing of inner-door panel of auto. The three parameters are yield stress $\sigma_s$, strain hardening exponent $n$ and normal anisotropic parameter $\gamma$. The sheet thickness is 0.7 mm. The clearance between punch and die is 0.25. The friction coefficient is 0.1 and unit sheet

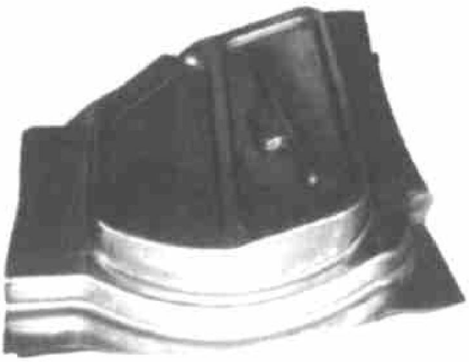

**Fig. 7** Inner-door panel of auto after two steps of drawing

holder forces of 2.5 MPa are used. At each time, only changing one value of the three parameters in numerical simulation. The simulation results are listed in Table 1.

## 4.1 Influence of $\sigma_s$ values

Setting $n$ = 0.23, $\gamma$ = 1.8, the $\sigma_s$ value is varied from 150 MPa to 250 MPa. The effects of yield stress $\sigma_s$ on the thickness change of the sheet are shown in Fig. 8. According to Fig. 8, we can conclude that $\sigma_s$ has large influence on the increase of thickness, but has little influence on the decrease of thickness in the sheet metal forming process.

## 4.2 Influence of $\gamma$ values

Setting $n$ = 0.23, $\sigma_s$ = 200 MPa, the $\gamma$ value is varied from 1.3 to 2.0. The influences of normal anisotropic parameter $\gamma$ on the thickness of the sheet are shown in Fig. 9. According to Fig. 9, we can conclude that a larger $\gamma$ value results in a smaller change of the sheet thickness, which shows the sheet has better flowability, and also means a larger $\gamma$ value can result in a better formability of the sheet.

## 4.3 Influence of $n$ values

Setting $\gamma$ = 1.8, $\sigma_s$ = 200 MPa, the strain hardening exponent $n$ value is varied from 0.17 to 0.25. The influences of $n$ on the thickness of the sheet are shown in Fig. 10. According to Fig. 10,

**Table 1** Simulated and experimental results of auto door panel for different materials

| Material parameter | | | Drawing load/kN | Thickness distribution in simulation/mm (Change ratio of thickness) | Thickness distribution in experiment/mm (Change ratio of thickness) |
|---|---|---|---|---|---|
| $\sigma_s$/MPa | $\gamma$ | $n$ | | | |
| 200 | 1.80 | 0.23 | 180.0 | 0.56 to 0.78 (−20.27%− to 11.83%) | 0.52 to 0.79 (−25.71% to 12.86%) |
| 150 | 1.80 | 0.23 | 161.0 | 0.56 to 0.78 (−20.63% to 11.36%) | 0.52 to 0.78 (−26.24% to 12.42%) |
| 175 | 1.80 | 0.23 | 170.5 | 0.56 to 0.78 (−20.61% to 11.64%) | 0.52 to 0.79 (−25.88% to 12.55%) |
| 225 | 1.80 | 0.23 | 180.0 | 0.56 to 0.78 (−20.62% to 11.82%) | 0.52 to 0.79 (−26.13% to 12.76%) |
| 250 | 1.80 | 0.23 | 180.0 | 0.55 to 0.78 (−21.07% to 11.83%) | 0.50 to 0.79 (−27.57% to 12.86%) |
| 200 | 1.30 | 0.23 | 176.9 | 0.54 to 0.80 (−22.45% to 14.40%) | 0.49 to 0.80 (−30.11% to 14.28%) |
| 200 | 1.50 | 0.23 | 180.2 | 0.55 to 0.79 (−21.63% to 13.22%) | 0.50 to 0.79 (−28.74% to 13.54%) |
| 200 | 1.65 | 0.23 | 180.5 | 0.56 to 0.79 (−20.66% to 12.49%) | 0.52 to 0.79 (−25.11% to 13.11%) |
| 200 | 2.00 | 0.23 | 180.6 | 0.56 to 0.78 (−19.96% to 11.07%) | 0.52 to 0.78 (−24.24% to 12.07%) |
| 200 | 1.80 | 0.17 | 179.5 | 0.56 to 0.78 (−20.27% to 11.83%) | 0.52 to 0.79 (−25.88% to 12.55%) |
| 200 | 1.80 | 0.19 | 179.9 | 0.56 to 0.78 (−20.26% to 11.83%) | 0.52 to 0.79 (−25.88% to 12.55%) |
| 200 | 1.80 | 0.21 | 180.1 | 0.56 to 0.78 (−20.27% to 11.83%) | 0.52 to 0.79 (−25.88% to 12.55%) |
| 200 | 1.80 | 0.25 | 180.3 | 0.56 to 0.78 (−20.27% to 11.83%) | 0.52 to 0.79 (−25.88% to 12.55%) |

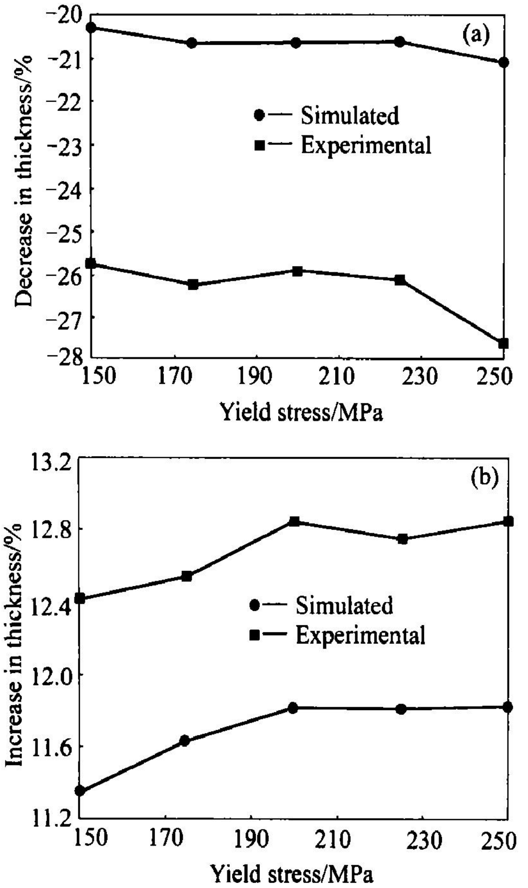


**Fig. 8** Effect of yield stress on thickness

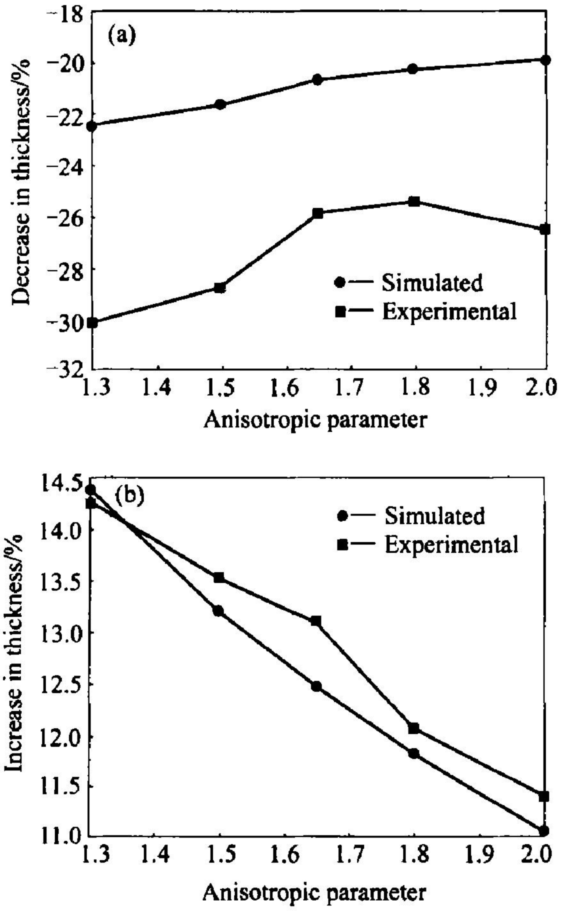


**Fig. 9** Effect of anisotropic parameter value on thickness

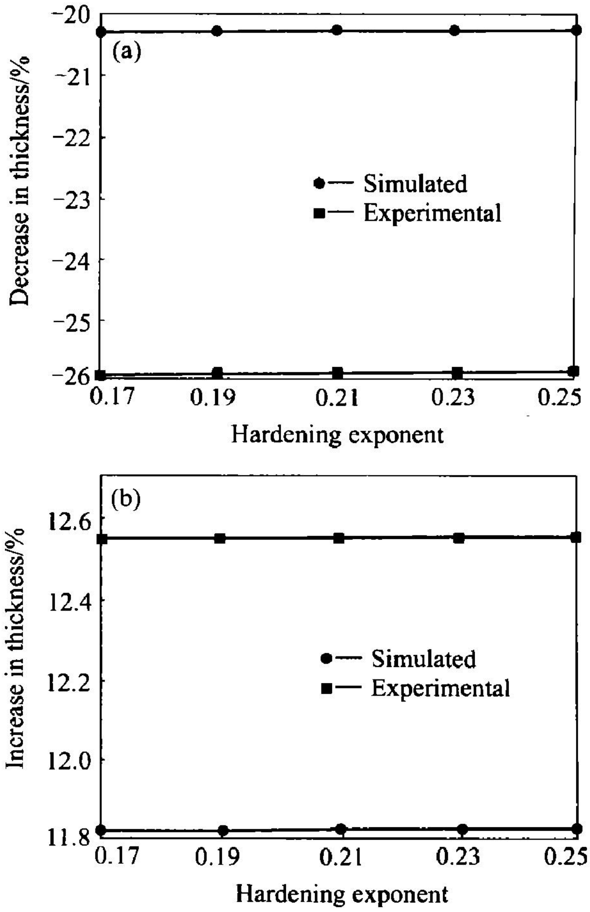


**Fig. 10** Effect of hardening exponent value on thickness

we can conclude that *n* value has little effect on the thickness change of the sheet.

From these figures, we can see that the experimental results agree well with the simulation results.

## 5 CONCLUSIONS

The forming features of complex sheet metal in two-stage deep drawing are analyzed, and then, the ideas and detailed work of the research on inner-door panel of auto in two-stage deep drawing are introduced. Two-stage deep drawing dies are designed to simulate the forming of inner-door panel of auto, and a large number of numerical and physical works are done to research the principle of complex sheet metal in two-stage deep drawing.

## REFERENCES

[1] Michler J R, Weinman K J, Kashani A R, et al. A strip-drawing simulator with computer-controlled drawhead penetration and blank holder pressure [J]. Journal of Material Processing Technology, 1994(43): 177 − 194.

[2] Doege E, Schulte S. Design of deep drawing components with elementary calculations methods [J]. J Mater Process Techno, 1990(34): 439 − 447.

[3] TAO H Z, CHEN Jun, RUAN Xue-yu, et al. The

physical simulation and numerical simulation in multi-stage deep drawing [J]. Automobile Technology and Material, 2000(4): 1－3. (in Chinese)

[4] TAO H Z, HE Dan-nong, RUAN Xue-yu, et al. The research on numerical simulation software technology of sheet metal [J]. Forging Machine, 1999(3): 46－49. (in Chinese)

[5] Park S B, Choi Y, Kin B M, et al. A study of computer-aided process design system for axisymmetric deep-drawing products [J]. J Mater Process Techno, 1998(75): 17－26.

[6] Demeri M Y. Drawheads in sheet metal forming [J]. J of Materials Engineering and Performance, 1993, 2(6): 863－866.

[7] HE Dan-nong, YIN Xiong-fei, TAO Hong-zhi, et al. Research on the evaluation method of friction and lubrication in deep drawing [J]. Acta Metallurgica Sinica, 2000, 2: 231－234.

[8] Shulkin L, Jansen S W, Ahmetoglu M A, et al. Elastic deflections of the blank holder in deep drawing of sheet metal [J]. J Materials Processing Technology, 1996, 59: 34－40.

[9] Barlat F, Lian J. Plasticity behavior and stretchability of sheet metals [J]. Int J Plasticity, 1989, 51: 51－66.

[10] Esche S K, Sudheer Khamitkar, Kinzell G L, et al. Process and design for multi-step forming of round parts from sheet metal [J]. J of Materials Processing Technology, 1996, 59: 24－33.

[11] Wang C T. Advanced stamping simulation technology: state of business and industrial prospects for the next century [A]. Proceedings of NUMISHEET'99 [C]. Besancon, France, 1999. 547－552.

[12] Wang N M, Somaratna N. Numerical simulation of industrial sheet forming processes [A]. Proc Numiform'89 [C]. Colorado, USA, 1989. 75－84.

**(Edited by YANG Bing)**