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OPTIMIZATION OF DEEP DRAWING PROCESS PARAMETERS OF 304 STAINLESS STEEL

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The one-step drawing process of double-box flume was simulated by finite element method(FEM). It was found that major defects in the forming process were vertical surface fractures in the box and material accumulation near rounded corners. The optimal forming parameters were obtained by optimizing and improving workpiece, single factor analysis and orthogonal experiment optimization. Guiding grooves with an included angle of 140° and a depth of 1 mm was designed in the blank holder to guide materials from accumulation area to insufficient area, thus reducing material fractures and improving deep drawing. The ultimate depth of one-step drawing without defects was increased to 190 mm by optimizing process parameters and improving structure.

Keywords: stainless steel, deep drawing, simulation analysis, process optimization, guiding groove

INTRODUCTION

The deep drawing of 304 stainless steel is a plastic forming process with large disturbance and deformation. The deformation of steel is affected by complex stress and strain under the interaction of bending and stretching [1]. It is difficult to design a cold stamping die for stainless steel with large forming depth. The deep drawing of sheet metal parts with box depends not only on material, but also on the reasonable selection of process parameters such as section size, drawing depth and drawing times [2-3]. It is more difficult to process the sheet metal parts with double boxes, especially one-step deep drawing. Currently, the production process of flume with large depth can be divided into four steps: initial drawing forming, annealing treatment, drawing to target depth and remolding, and it requires higher cost and more time [4]. Therefore, higher productivity can be achieved if the depth of flume can be drawn more than 90 % in one-step deep drawing.

In this paper, based on simulation analysis, the optimized forming process parameters were obtained by orthogonal test, then material flow was guided by improving blank holder structure for one-step deep drawing, so as to improve the drawing depth and quality.

ANALYSIS OF STRUCTURE AND PROCESS

The structural shape of double-box flume is shown in Figure 1. The sizes of boxes are 410 × 400 × 190 mm and 335 × 400 × 190 mm respectively with a dimensional accuracy of grade IT14, and the material is 304 stainless steel with a thickness of 0,8 mm. Due to the large depth of double boxes, it was difficult for the flume to mold by one-step drawing, so four-step drawing was applied, resulting in more molds and lower production efficiency [5]. The workpiece was pressed on the fixed female die through blank holder and the punch moved downward to pull the workpiece out, as shown in Figure 2.

Figure 1 Product model

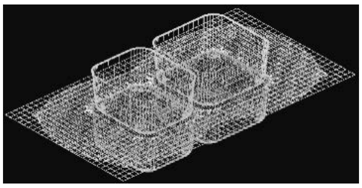

Figure 2 Simulation model of drawing process

FINITE ELEMENT ANALYSIS OF DRAWING

Simulation of forming process

The shape and size of workpiece is one of the important factors affecting product quality. DYNAFORM was used to directly map the product geometry to plate blank, and necessary constraints were applied to simulate and predict the possible cracking and wrinkling trends, so as to provide reference for improving product design and

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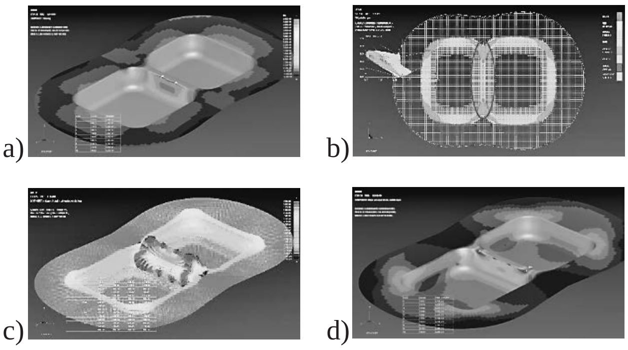

Figure 3 Simulation of drawing process (a) Thinning rate of blank (b) Material displacement (c) Strain vector (d) Maximum strain

Table 1 **Drawing parameters**

Unit blank holder force / MPa	3,5
Model clearance / mm	1,1x0,8
Friction coefficient	0,1
Fillet Radius of Punch / mm	25
Fillet Radius of Female Die / mm	5

die process design [6-7]. After workpiece was reversely calculated, deep drawing process was simulated and analyzed according to process parameters shown in Table 1.

The forming state of drawing process is shown in Figure 3. Figure 3(a) indicates that the region with the largest material thinning rate was the vertical plane adjacent to two boxes. As shown in Figure 3(b), the material displacement in the vertical plane was the largest while that near the rounded corners was the smallest.

It can be seen from Figure 3(c) and Figure 3(d) that maximum strain was concentrated in the plane connecting the two boxes, indicating that this area was prone to fracture due to the maximum stress and strain sustained during the forming process, mainly because material flew in multiple directions. When materials flew to drawing direction, it also flew to adjacent box, forming a connecting plane at the intersection of the two boxes. Consequently, materials in this region are subject to greater tension and deformation. As fracture was a major defect in the drawing process, and the connection area between the two boxes was most prone to fracture, it is necessary to optimize the process parameters to avoid fracture.

Optimization and verification of process parameters

Combined with the influence of drawing process and material properties, five factors including workpiece holder force, die clearance, friction coefficient and radius of punch and female die were selected as the process parameters for orthogonal experiment and the fracture of samples in the process of drawing was analyzed. A total of 16 groups of samples were numerically simulated by DYNAFORM to obtain the forming limit state and analyze the drawing limit depth and forming quality of each test group. According to the orthogonal test, the optimal drawing process parameters of double-box stainless steel flume were obtained as follows: workpiece holder force was 3,0 MPa, die clearance was 1 095 x 0,8 mm, friction coefficient was 0,05, punch fillet radius was 25 mm and female die fillet radius was 11 mm. These parameters were used for further simulation analysis.

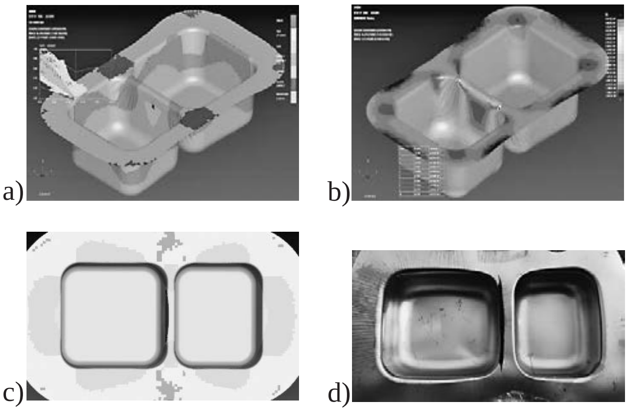

Figure 4 Simulation and experimental results. (a) Forming limit diagram (b) Thinning rate of material (c) Fracture state (d) Experimental product

As can be seen from Figure 4(a) and Figure 4(b), the forming limit and maximum thinning rate were concentrated in the vertical surface adjacent to small box in the large box. When drawing depth was 163 mm, the sheet was broken in this region. The fracture area predicted by simulation is shown in Figure 4(c), which is consistent with that of the experimental products in Figure 4(d), verifying the reliability of finite element analysis.

PROCESS IMPROVEMENT FOR OPTIMIZING MATERIAL FLOW

Design of material flow guide groove

According to the above simulation analysis, the material in the connecting platform between the two boxes flows out from region A, while the material near the rounded corners mainly flew out from region B, as shown

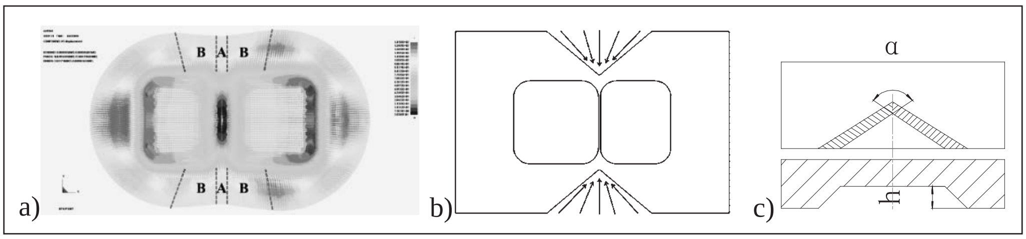

Figure 5 Material distribution and flow. (a) Material distribution (b) Groove for guiding material flow (c) Structure of guiding groove

in Figure 5(a). The forming defect was that the material connecting the platform was in short supply and easy to break, while there were too many materials around the rounded corners and they were easy to wrinkle. As shown in Figure 5(b), it is a feasible method to guide the material from wrinkle area to the fracture area, so as to make the material distribution more balanced.

Due to the impact of blank holder force on material flow, a guiding groove with a depth of *h* and an included angle of *a* was designed in the regions A and B as shown in Figure 5(c) to reduce the pressure on the plate and guide the material in the region B to flow more smoothly to middle regions so that excessive material near rounded corners flew into connecting platform where material was in short supply in the process of forming, ultimately making material more uniformly formed.

Influence of guiding groove on material flow and forming quality

Obviously, the depth and angle of guiding groove play a decisive role in the material flow. The forming process was simulated by changing depth when angle remained unchanged. As can be seen from Figure 6, with the increase of depth, the space for material flow increased, leading to more serious material accumulation. When depth was 1 mm, guiding groove could guide the material to flow to the middle region in an orderly manner, and the material wrinkled slightly on the edge of the flume and could be treated by shaping.

The comparison of the forming quality without guiding groove and with guiding groove h = 1 mm, α = 100 - 140° is shown in Figure 7. According to the figure, as the angle increased, the node displacement and maximum drawing depth without fracture increased and thinning rate decreased, indicating that material exhibited better fluidity and was not easy to fracture.

Optimization of deep drawing process

Based on the finite element analysis of forming quality and material flow, the guiding groove was designed for material flow on the basis of the original forming process, and the forming process parameters were optimized, as shown in Table 2.

It can be seen from the forming limit diagram in Figure 8(a) that when the flume was drawn to a depth of 190 mm in one-step drawing process, rounded corners and the connecting platform of the two boxes are prone to fracture, but material was not broken, most of which were safe, and the wrinkling areas on the upper edge of the flume plane could be eliminated by subsequent finishing process. As shown in Figure 8(b), there was no crack and the edge of big box was wrinkled when the

Table 2 **Optimized process parameters**

Unit blank holder force / MPa	3,0
Model clearance / mm	1 095 x 0,8
Friction coefficient	0,05
Fillet Radius of Punch / mm	25
Fillet Radius of Female Die / mm	11
Depth of groove / mm	1
Angle of groove / °	140

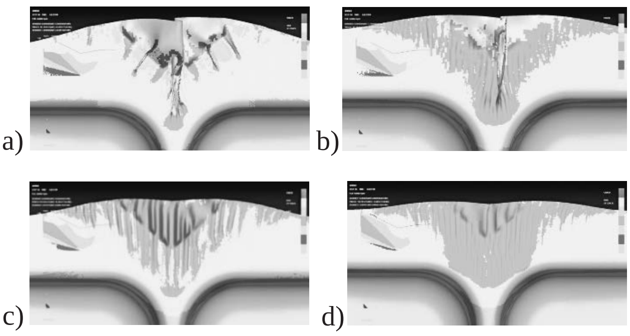

Figure 6 Influence of guiding groove depth on forming quality (a) h= 20 mm (b) h = 10 mm (c) h = 5 mm (d) h = 1 mm

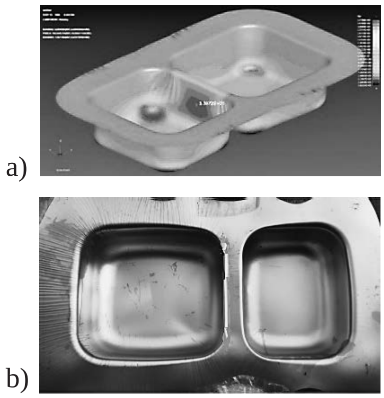

Figure 8 Comparison of simulation and experiment after process optimization. (a) Forming limit diagram (b) Experimental product

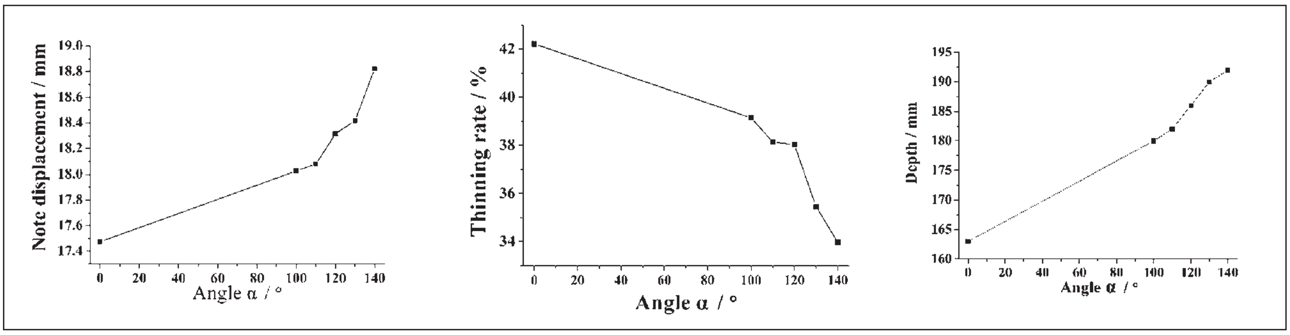

Figure 7 Influence of a on forming quality. (a) Displacement of node flow (b) Thinning rate (c) Drawing depth

product was drawn to a depth of 190 mm. The experimental results are consistent with the simulation results, which proved that the finite element simulation was accurate, and guiding grooves in the blank holder could effectively improve the drawing depth and forming quality.

CONCLUSIONS

(1) Through simulation and experiment, it is found that the main defects in the drawing process of double-box flume are the vertical surface fracture in the box and wrinkles around rounded corners.

(2) With the method of orthogonal experiment optimization, the optimal forming parameters without fracture in one step drawing are obtained The optimum forming parameters of one-step drawing without fracture are obtained as follows by orthogonal test: unit blank holder force is 3,0 MPa, die clearance is 1 095 x 0,8 mm, friction coefficient is 0,05, fillet radius of punch is 25 mm, and fillet radius of female die is 11 mm. Using these parameters, the depth of one-step drawing is obtained to be 163 mm.

(3) Guiding grooves with a depth of 1 mm and an included angle of 140° designed for the blank holder can effectively guide the flow of material from accumulation area to insufficient area. The drawing depth and forming quality can be improved effectively by optimizing workpiece holder and optimizing orthogonal parameters. The experimental results show that the drawing depth can be increased to 190 mm without fracture in this scheme.

Acknowledgements

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Note: The responsible translator for the English language is Z. W. Li, Ningbo, China