

## Research on the process of stretch forming based on distributed displacement loading

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**Keywords:** Stretch forming, distributed displacement loading, curved surface.

**Abstract.** A new stretch forming process based on distributed displacement loading for three-dimensional surface parts is proposed, the external stretching displacement load is applied at a series of discrete points, so the flexibility of the loading mechanism is improved. The forming process can be realized by controlling the loading trajectory at each discrete point and the formed part with the thickness uniformly distributed are obtained. In order to investigate the influence of the loading time-steps on the forming results in the in the process of stretch forming three-dimensional surface part based on distributed displacement loading, the forming process with three different time-steps were numerical analyzed. By analyzing the numerical results, it can be concluded that the more loading time-steps is, the smaller the shape error will be stretch forming three-dimensional surface part based on distributed displacement loading.

### Introduction

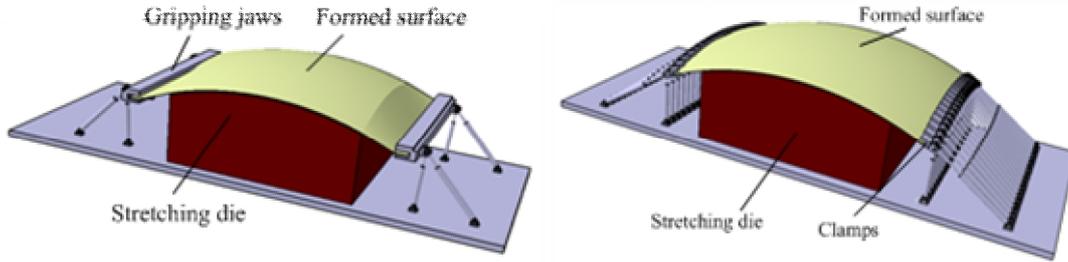
Stretch forming operations are widely used in the aerospace industry, which is a very important method to form three-dimensional surface parts [1]. In the traditional stretch forming process, rigid gripping jaw was used and the sheet metal end undergoes a uniform displacement, easily leading to the occurrence of defects such as wrinkle, severely local deformation, or even material failure [2]. Since the low flexibility of the traditional loading mechanism, the defect of incomplete conformability of sheet metal to forming die may usually occur when the parts with complicated shape are formed. Multi-gripper stretch forming is proposed and the traditional loading mode of gripping jaw is changed [3]. Extensive investigations on the processes of forming three-dimensional surface parts have been conducted [4,5], but its forming process is controlled using force loading. A new stretch forming process based on distributed displacement loading for three-dimensional sheet metal part is proposed [6], the external stretching load is applied at a series of discrete points. The process presents a better ability to form sheet metal parts, because the displacement at each discrete loading point can be controlled individually, the forming quality of the sheet metal is then be improved.

The main purpose of this paper is to investigate the influence of the loading mode and the number of loading time-steps on the forming result. The forming processes with different loading modes for spherical part are simulated, to discuss the influence of the loading time-steps on accuracy of the formed part, the forming processes with three different loading time-steps for spherical part are numerical analyzed

### Description of Stretch-forming Process Based on Distributed Displacement Loading

Stretch forming with distributed displacement loading is derived from the idea of traditional stretch forming and the multi-point forming. Fig.1 shows the structure diagrams of two different stretch forming apparatuses. In the stretch forming process with distributed displacement loading, the traditional loading mode of gripping jaw is replaced by distributed displacement loading mode, the

stretching load is applied at a series of discrete points on the two ends of sheet metal. By controlling the loading trajectory at the each discrete point, a satisfied forming result can be obtained.



**Fig. 1** Structure diagrams of two different stretch forming apparatuses **a.** Traditional stretch forming **b.** Stretch forming based on distributed displacement loading

## Loading Trajectory Design for Spherical Parts

### Traditional Loading Mode

Spherical part is one kind of widely used three three-dimensional curved surface parts, so the loading trajectory of stretch forming spherical surface is designed. In the traditional stretch forming process (TSF), the sheet metal end undergoes a uniform displacement, the displacement of the jaw should be:

$$\begin{cases} \Delta x = r_0 \sin q_0 + [l_0 - r_0 q_0] \cos q_0 - l_0 \\ \Delta y = r_0 \cos q_0 - [l_0 - r_0 q_0] \sin q_0 - R \end{cases} \quad (1)$$

where  $l_0$  is half the length of the initial blank sheet and  $R$  is the radius of the spherical part,  $r_0 = \sqrt{R^2 - z_0^2}$  and  $z_0$  is the  $z$ -coordinate of the transversal edge of the spherical part,  $q_0 = \arcsin(b_0 / r_0)$  and  $b_0$  is half the length of the forming die.

### Distributed Displacement Loading Mode

In the process of stretch forming with distributed displacement loading (DDLSF), the initial sheet metal is bent into a cylinder in contact with the die surface by controlling the movement of each point, and then the cylinder of sheet metal is stretch formed into a spherical surface part. It is assumed that the length of the longitudinal fiber on the edge line of the spherical surface is unchanged, the elongation of a longitudinal fiber will be:

$$\Delta l(z) = r_0 \arcsin(b_0 / r_0) - r \arcsin(b_0 / r) \quad (2)$$

If the external load is applied by  $n$  time-steps, the displacement of loading point  $i$  at  $j$ th time-step can be expressed as follow:

$$\begin{cases} \Delta x_j(z_i) = r_i \sin q_j + [l_0 + \Delta l_j - r_i q_j] \cos q_j - l_0 \\ \Delta y_j(z_i) = r_i \cos q_j - [l_0 + \Delta l_j - r_i q_j] \sin q_j - r_i \end{cases} \quad (3)$$

where  $r_i = \sqrt{R^2 - z_i^2}$  and  $z_i = (i - 0.5)D / 10$ ,  $D$  is the half the width of the formed surface.  $\Delta l_j = j \Delta l(z_i) / n$  and  $q_j = j \arcsin(l_0 / r_i) / n$ .

### FE Model

The radii of curvatures in two principal directions of the target spherical surface are  $R=500$ mm and thickness 1mm, the size of initial sheet metal is  $2l_0=400$ mm and  $D=300$ mm. The material of sheet metal used in the numerical simulation is aluminum alloy 2024-O sheet, the relevant mechanical properties are: density  $\rho=2780$  kg/m<sup>3</sup>, elastic modulus  $E=40.6$  Gpa, Poisson's coefficient  $\nu=0.33$ , the yield strength  $s_y=75.3$  Mpa, and the tensile strength  $s_b=191$  Mpa. The length and the width of the stretching die are both 300 mm.

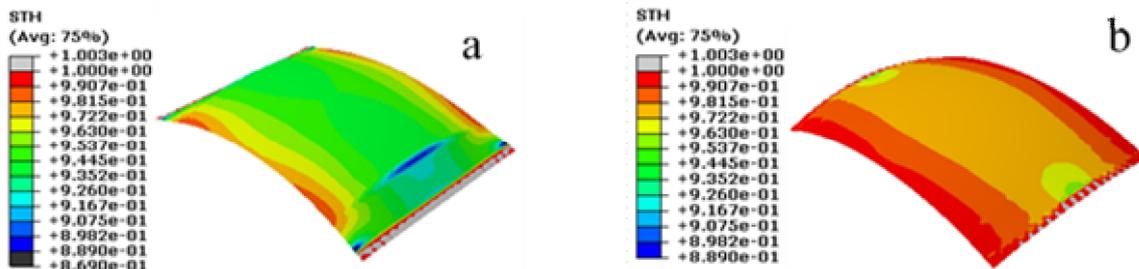
The explicit dynamic version of ABAQUS/Explicit was chosen to simulate the stretch forming processes. Due to the symmetry, only a quarter of the finite element models were modeled. The rigid

surface of the die was modeled with R3D4 elements as well as the clamping parts, and the sheet metal was modeled with S4R elements. In order to avoid the spurious deformation modes in the finite element simulations, the default hourglass control algorithm was adopted for the sheet metal.

## Numerical Simulation Results and Discussions

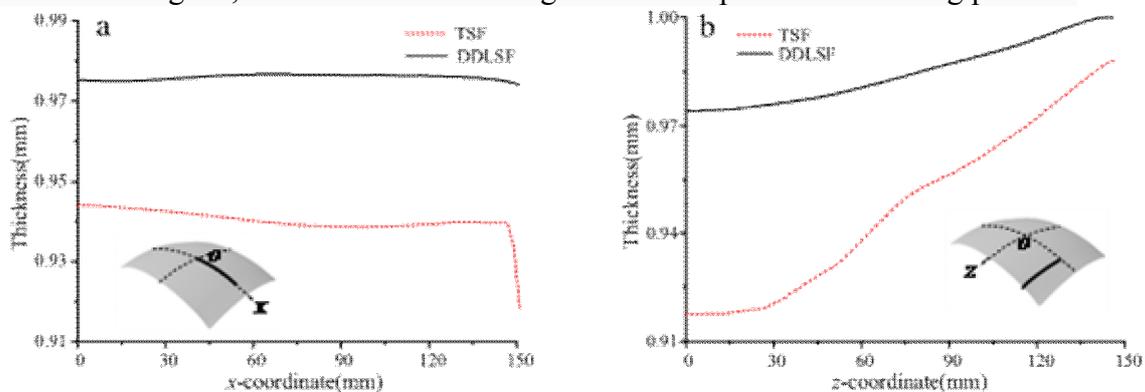
### Effect of Loading Mode on Thickness Distribution

Fig.2 compares the thickness distributions of spherical parts formed with two different loading modes (TSF and DDLSF). It can be seen that the thickness reduction in the effective forming area on the spherical part formed with DDLSF is smaller than that on the spherical part formed with TSF. The thickness distribution on the part formed with DDLSF is more uniform.



**Fig. 2** Thickness distributions on the part formed with two different loading modes **a.** TSF **b.** DDLSF

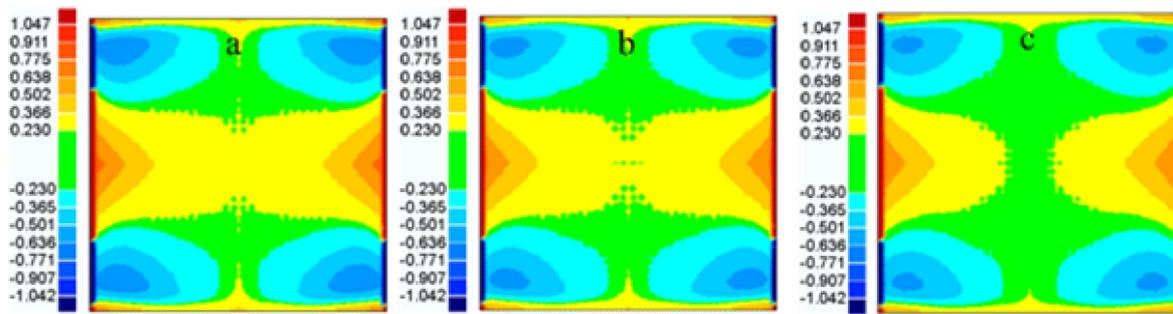
Fig.3a displays the thickness distributions along the transverse centerline on the formed parts and Fig.3b shows the thickness distributions along the longitudinal edge line of the effective forming area. It can be easily found that the magnitude of thickness variation and the average thickness distribution on the part formed with DDLSF are smaller than those on the formed part corresponding to TSF. A sudden decrease in thickness of the sheet metal occurs at the area contacted with longitudinal edge of the stretch forming die, when traditional loading mode is adopted in the forming process.



**Fig. 3** Distribution of thickness in the effective forming area **a.** along transverse centerline **b.** along longitudinal edge line

### Effect of Loading Time-steps on Shape Error Distribution

In order to investigate the effect of the loading time-steps on the forming results in the process of stretch forming sheet metal part, the forming process with 1,5,10 time-steps were numerical analyzed. Fig.4 shows the shape error distribution between desired surface part and the numerical result corresponding to different loading time-steps. It can be seen that the shape error corresponding to 10 time-steps is the smallest. It can be concluded that the shape error decreases with the loading time-steps increasing in the forming process.



**Fig. 4** Shape error distributions on the spherical surface **a.** 1 time-step **b.** 5 time-steps **c.** 10 time-steps

## Conclusions

Stretch forming based on distributed displacement loading is a new means for sheet metal part. The external stretching load is applied at a series of discrete points on the each end of the sheet metal, so the flexibility of the loading mechanism is improved. The stretch forming processes for spherical parts with traditional loading mode and distributed displacement loading mode were numerical analyzed. It can be founded that the thickness reduction on the surface part formed with distributed displacement loading mode is smaller than that on the part formed with traditional loading mode through numerical analysis.

By analyzing the numerical results corresponding to different loading time-steps, it can be concluded that the shape error decreases with the loading time-steps increasing in the process stretch forming three-dimensional surface part based on distributed displacement loading.

## Acknowledgements

The authors would like to acknowledge the financial support provided by the National Nature Science Foundation of China (51575231).

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