The effect of the model posture on the forming quality in the CNC incremental forming

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Abstract. Sheet rupture caused by a sheet metal thickness non-uniformity persists in CNC (Computer Numerical Control) incremental forming. Because the forming half cone angle is determined by the orientation of the model to be formed, so is the sheet metal’s uniformity. The finite element analysis models for the two kinds of the postures of the model were established, and the digital simulation was conducted by using the ANSYS/LA-DYNA software. The effect of the model’s posture on the sheet thickness distribution and the sheet thickness thinning rate were studied by comparing the simulation results of two kinds of the finite elements analyzes.

1. Introduction

The sheet metal CNC incremental forming is a flexible dieless forming technology adopting the idea of layered manufacturing [1-3]. The fundamental principle of sheet metal CNC incremental forming consists of the model to be formed being put in a certain direction (pressing direction) and the sheet metal being pressed point by point along the forming tool path [4, 5]. However, the problem of the thickness non-uniformity of the sheet metal part and easy rupture in the part of the big curvature is still relevant for the CNC incremental forming. In the forming process, the final thickness $t_1$ is dependent on the initial blank thickness $t_0$ and the forming half cone angle $a$, as given by $t_1 = t_0 \sin a$ [6-8], moreover, the half cone angle $a$ is dependent on the posture of the model to be formed. Therefore, the posture of the model has a significant impact on the thickness thinning and distribution of the sheet metal. The optimization of the model posture, however, is also of a great importance [9, 10].

In this paper, the effect of the model posture on the forming quality has been discussed through the CNC incremental forming digital simulation process of the different posture models using the digital simulation technology based on the finite element analysis (FEA).

2. The establishment of the finite element analysis model

In order to compare and analyze the thickness distribution and thinning rate of the sheet, the ANSYS/LS-DYNA software is used for digital simulation. Figure 1(a) shows the original model posture. Figure 1(b) shows the model with a posture optimized according to the method of Zhu, Zhang and Ju [9], and with a surface reconstructed according to the method of Zhu, Zhang and Ju [11].

The two types of finite element analysis models of the CNC incremental forming process are

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established for the two types of models, i.e. the original posture of the model and the optimized posture of the model as shown in Figure 2. The analysis model is composed of the following elements: the pressing tool heads, the sheet metals, and supports. The sheet metals are two square blank sheet metals the length and width of which are 100 mm×80 mm and 120 mm×100 mm respectively. Ball head part of the pressing tool contacting sheet metal is reserved and simplified as a sphere with a radius of 3 mm. The necessary CAD model of the support is obtained by offsetting the outside surface of the sheet metal model 1 mm inwards. Figure 3(a) and 3(b) show the support models generated on the basis of the original model (the green model) and the posture optimized model (the green model) respectively.

![Figure 1](image1.png)

*Figure 1. Case study model: (a) Original model; (b) Posture optimized model.*

![Figure 2](image2.png)

*Figure 2. The finite element analysis model.*

![Figure 3](image3.png)

*Figure 3. Support model.*

2.1. The finite element analysis condition setting
The SHELL 163 element was used in order to define the sheet metal, and the SOLID 164 element was adopted in order to define the support and the pressing tool [12]. The sheet was defined as a transversely anisotropic hardened plastic model, namely Al1060 aluminum sheet. The rigid body material model was used for the support and the pressing tool head, namely bearing steel GCr15. The sheet was meshed by the mapped meshing with a size of 1 mm, the pressing tool head was meshed by the free meshing with a size of 1 mm, and the support was meshed by the free meshing with a size of 4 mm.

2.2. Description of pressing movement
In this paper, the vertex offset method of Qu and Stucker [13] was used. In order to generate an equidistant surface for the forming tool path, the outer surface of the sheet part model was offset 3 mm towards the outside equaling the distance of the pressing tool radius. Then, in order to obtain the contour line path, the equidistant surface was cut with the plane vertical to Z axis with a spacing distance of 1 mm, and it was dispersed into a serious of path points which were put into the ANSYS system to load. The generated forming path is shown in Figure 4.

3. Results of the finite element analysis
3.1. Comparative analysis of the sheet thickness distribution

Figure 5(a) and 5(b) show the cloud pictures for the sheet thickness distribution of the finite element analysis. Figure 5(a) shows the digital simulation result in the sheet CNC incremental forming process based on the original model, the minimum final sheet thickness is 0.5140 mm and concentrates on the area of the higher pressing angle. However, the digital simulation result in the sheet CNC incremental forming process based on the optimized model shows the uniform sheet thickness distribution, the minimum final sheet thickness is 0.6107 mm. It is evident that the minimum sheet thickness has been increased by 0.0697 mm due to the model posture optimization (Figure 5(b)).

As shown in Figure 6(a), on the outline of the middle surface parallel to the Y axis: for the original posture of the model, the minimum sheet thickness is 0.718 mm at the section of x>0; for the optimized posture of the model, the minimum sheet thickness is 0.745 mm at the same section of x>0, the minimum sheet thickness has increased by 0.027 mm, therefore, the thickness of the sheet is more uniform. As shown in Figure 6(b), on the outline of the middle surface that is parallel to the X axis: for the model’s original posture, the minimum sheet thickness is 0.579 mm at the section of y<0; for the model’s optimized posture, the minimum sheet thickness is 0.665 mm at the section of y>0, the minimum sheet thickness has increased by 0.086 mm, therefore, it can be concluded that the sheet thickness of the posture optimized model is more uniform than the posture of the non-optimized model. It is evident from the positive and negative sides of the X and Y axes that the thickness difference on both sides of the model has decreased after the posture of the model was optimized.
Before the model’s posture optimization, the model thickness difference is 0.183 mm along both sides of the X axis and 0.226 mm along both sides of the Y axis. After the model’s posture was optimized, the model thickness difference is 0.088 mm along both sides of the X axis and 0.041 mm along the both sides of the Y axis.

As the forming angle’s difference is large along the direction, the thickness uniformity along the Y axis is observable. But the effect of model-posture-optimization is not significant along the X axis because the forming angle’s difference along the X axis is not big enough.

3.2. Comparative analysis of the sheet thickness thinning rate

The sheet thickness thinning rate’s cloud pictures are shown in Figure 7. The CNC incremental forming’s digital simulation results, based on the original model, show that the thickness thinning is concentrated around the area with the bigger forming angle, which has a maximum sheet thickness thinning rate of 45.81% (Figure 7(a)). However, the digital simulation result of the CNC incremental forming, based on the posture optimized model, portray a more uniform sheet, with a maximum sheet thickness thinning rate of 37.67%. The sheet thickness thinning rate decreased by 8.2% due to the model’s posture optimization (Figure 7(b)).

![Cloud pictures of sheet thickness thinning rate](image)

**Figure 7**. Cloud pictures of sheet thickness thinning rate.

As shown in Figure 8(a), on middle surface’s outline that is parallel to the Y axis, before the posture optimizing, the maximum sheet thickness thinning rate is 28.91% at the section of $x>0$, while after the posture optimization, the maximum sheet thickness thinning rate is 24.86% at the section of $x>0$. The difference of the maximum sheet thickness thinning rate’s difference is 4.05%. Figure 8(b) portrays, on the outline of the middle surface that is parallel to the X axis, that before the posture was optimized, the maximum sheet thickness thinning rate lays at 41.74% for $y<0$, while after the posture optimizing, the maximum sheet thickness thinning rate scores 28.98% at the section of $y<0$ and 33.23% for $y>0$. Therefore, the maximum sheet thickness thinning rate is 33.23% and the difference between them is 8.54%. Before the model’s posture optimization, the model thinning rate’s difference on both sides
lays at 19.805% on the outline of the middle surface which is parallel to X axis. After posture optimizing, the thinning rate’s difference on both sides of the model is 8.598%. Before model posture optimizing, the maximum difference for the thinning rate on both sides of the model is 22.671% on the outline of the middle surface which is parallel to the Y axis. After posture optimizing, the model thinning rate’s maximum difference on both sides is 4.368%. Thus, the sheet thickness thinning rate distribution is more uniform after the model posture optimizing on the both sides of the X and Y axes.

4. Conclusions

The finite element analysis results of the CNC incremental forming show that the model posture has a direct effect on the sheet thickness distribution and the thickness thinning rate. The effect of the model posture is especially important when the curative difference of the surfaces is large. The sheet thickness difference and distribution non-uniformity can be decreased by optimizing the model posture reasonably, which can also help avoiding the rupture problem caused by the large differences of the sheet thickness and distribution non-uniformity.

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