Research on Cutting Path Optimization of Trimming Process

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Abstract. For a stamped part, excess material on the edge need to be cut to get the final part. To explore the impact of different laser-cutting paths on the accuracy of part formed by multi-point forming with blank-holder, three different cutting paths are designed in this paper, and the process of laser-cutting is simulated by finite element method. By comparing the springback of the parts under different cutting paths, it is found that the part cut by path 3 has the highest accuracy. Finally, the experiment is performed with path 3 and compare the shape of the formed part with the target part, it is verified that cutting with path 3 can obtain higher precision parts.

1. Introduction
Multi-point forming (MPF) is a new stamping process [1]. MPF with blank-holder effectively suppresses wrinkle defects of formed parts. However, due to blank holder operation, a lot of residual stress is generated inside the formed part, and the shape accuracy is significantly affected after trimming.

Laser-cutting is the most widely used among many cutting methods due to its advantages such as high efficiency, easy adjustment of power, and little affect in the process. In order to learn more about the principle of laser-material interaction, optimize parameters, and predict the machining process well, experts and scholars at home and abroad have proposed many simulation analysis methods of laser processing through computer technology, and established corresponding mathematical models[2].

In this paper, the finite element analysis method is used to simulate the trimming process of the part formed by MPF. The trimming process is realized by laser-cutting and the springback of the part formed by MPF under different cutting paths is discussed to find the best cutting path that has the least impact on the shape accuracy.

2. Establishment of finite element model
The analysis of laser-cutting temperature field is a nonlinear transient heat conduction problem. Analytical equations for nonlinear transient heat conduction problems are

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k \left[ \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right] + Q = c \rho \frac{\partial T}{\partial t}
\] (1)

In the formula, Q is the internal heat source, c is the specific heat capacity of the material, and \( \rho \) is the material density.
The laser cutting process is the coupling effect of temperature, stress, and deformation, that is, it involves thermal-mechanical coupling analysis in the finite element analysis. Therefore, the thermophysical constitutive model of the material should be used to solve between deformation and thermal analysis.

The purpose of this simulation is to obtain a spherical part with a forming radius of 1250mm. The rectangular sheet size used is 600mm × 800mm × 1mm. After the MPF with blank-holder is completed, the boundary of the part is cut off, and leaving a spherical pieces with the final size as 400mm × 400mm spherical surface. The material is Q345, and its thermophysical parameters are shown in Fig.1 [3], [4], [5], [6].

![Figure 1. Thermophysical parameters of Q345](image)

Firstly, a finite element model of the multi-point forming process is established, which consists of the upper die, the lower die, blank-holder, polyurethane elastic pad and sheet. The polyurethane elastic pad can eliminate the indentation defects which are generated during the process. Fig. 2a is a finite element model of MPF with blank-holder.

![a. The MPF with blank-holder](image)  ![b. Laser-cutting](image)

**Figure 2. The finite element model**

Then the finite element model of laser-cutting is established. In the process of laser-cutting simulation, the definition of the laser heat source model mostly involves the secondary development process of the software. The Load module provides users with different ways to define heat sources. In conjunction with the user subroutine DFLUX provided by the software, the laser heat source model is defined. The laser heat source model in this paper uses the Goldak double ellipsoid heat source. The DFLUX subroutine applies a heat source model to the sheet in the form of a programming language,
cooperates with the material damage criterion, and defines the material properties USDFLD. When the element's temperature reaches the material melting point where the heat source is applied, the element is deleted to achieve the purpose of material removal. The laser-cutting process uses the Dynamic temp-disp explicit algorithm to calculate the thermo-mechanical coupling process. Using the above finite element model, the stress-strain state after sheet forming and springback is taken as the initial state of laser-cutting, and the simulation of laser-cutting is performed on the part formed by MPF. The finite element model of the laser-cutting process is shown in Fig. 2b.

3. The analysis of laser-cutting

The springback can be considered as the reverse elastic deformation process caused by the residual stress release after the cutting of the part formed by MPF with blank-holder.

Fig. 3 is the cloud diagram of the residual stress distribution on the upper and lower surfaces of the formed part before laser-cutting. From the figure, it can be seen that the stress distribution at the edge of the part is concentrated, which is significantly larger than other zone. In the process of cutting, the cutting direction and position is different, the effect of stress release is different, and meanwhile, the effect on the shape accuracy is different.

![Figure 3. Cloud diagram of residual stress distribution on the upper and lower surfaces of the formed part before laser-cutting](image)

In this paper, three different cutting paths are adopted under the condition that the laser heat source has the same power and moves at the same speed. The laser-cutting simulation is performed on the part formed by MPF to find the best cutting path. Fig. 4 is the schematic diagram of three cutting paths. In Fig. 4, the black solid line is the outer contour of the formed part, and the red solid line is the boundary line of the area to be cut. A, B, C, D are the four vertices of the square area to be cut, and E, F, G, H are the midpoints of the AB, BC, CD, and DA edges, respectively. Among them, the path 1 uses A as the starting point and performs laser-cutting counterclockwise along A-B-C-D-A; The path 2 uses A as the starting point and alternately cuts the formed parts along AB, CD, BC and DA in turn. The path 3 starts with A and cuts along AE, BF, CG, DH, EB, FC, GD, and HA in that order.
Fig. 4. Three cutting paths

Fig. 5 is the cloud diagram of springback distribution after cutting with three paths and Fig. 6 is the comparison of springback curve in OD direction (O is the midpoint of the diagonal BD of the cutting area). It can be clearly seen from the figure that the part cutting with the path 1 has the largest springback, the part cutting with the path 2 smaller, and the part cutting with the path 3 have the smallest springback, that is, the path 3 has the smallest effect on the shape accuracy of the formed part when cutting. When the path 1 is used for cutting, as the laser heat source is swept along the A-B-C-D-A sequence, the vertex B, C, D, A is released in sequence, separated from the formed part in turn and free from restraint, so the springback value is greater; When using the path 2, the sides AB and CD are cut first and the residual stresses is released first, but at this time, the vertex of A, B, C, D is not separated from the edge region, which suppresses the springback of the formed part, it is not until cutting at the BC side that the B vertex is first separated from the formed part, so the springback is less than the path 1; when using the path 3, the four sides are cut by half the length first. Residual stress is preferentially released in these four places, and because the vertex of A, B, C, D is still not separated from the formed part, the springback of the formed part is also suppressed, and then the remaining half of the length is gradually cut to achieve the purpose of separation from the edge region. Therefore, the path 3 has least influence on the shape accuracy after laser-cutting of the formed part than the former two.

Fig. 5. Cloud diagram of springback distribution after cutting with three paths

Fig. 6. Comparison of springback curve in OD direction
4. Experiments

LMR 3D multi-axis intelligent laser-cutting equipment is used to cut. Fig. 7 is experimental equipment and finished products cut by path 3.

![Figure 7. Experimental equipment and finished products](image)

The 3DSS 3D scanner is used to scan the shape of the formed part and compare it with the shape before cutting. The springback distribution cloud diagram is shown in Fig. 8, springback gradually increases from the center of the formed part to the periphery, and it accords with reality. Fig. 9 is a comparison of the springback curve in the OD direction of the experiment and simulation. The results show that the experimental results are consistent with the simulated results (maximum error is only 0.073mm).

![Figure 8. The springback distribution cloud diagram](image)

![Figure 9. Comparison of the springback curve of the experiment and simulation](image)
5. Conclusion
When the laser heat source has the same power and the heat source moves at the same speed, different cutting paths are used to perform laser-cutting on the MPF with blank-holder, which has different effects on the shape accuracy of the formed part. In this paper, three different cutting paths were used for numerical simulation and experimental validation of laser-cutting of the part formed by MPF was conducted, which proves that the path 3 has the least influence on the shape accuracy after cutting.

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