Research on Process Parameters Optimization of Fine Blanking for Intermediate Washer of Clutch Based on Orthogonal Test

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Abstract. Intermediate washer of automobile clutch is taken as research object, blanking clearance, radius of corner of punch, blanking speed, blank holder force, counter force and tooth angle of blank holder are selected as influencing factors, length of shear zone is chosen as evaluation index. Orthogonal test with six factors and three levels is established, and Deform-2D is used to simulate fine blanking process of intermediate washer at different combinations of process parameters. Blanking clearance has a significant influence on length of shear zone by variance analysis. The influence sequence of fine blanking process parameters on length of shear zone is blanking clearance, counter force, radius of corner of punch, blank holder force, blanking speed and tooth angle of blank holder. In addition, the optimal combination of process parameters of fine blanking for intermediate washer are as follows: blanking clearance is 8%, radius of corner of punch is R0.09 mm, blanking speed is 15 mm•s\(^{-1}\), tooth angle of blank holder is 45°, blank holder force is 450 kN and counter force is 150 kN. The simulation value and experimental value of length of shear zone for optimized scheme are 3.945 mm and 3.438 mm respectively, the relative error between simulation value and experimental value is 12.9%. Therefore, it provides an important reference for the actual production of enterprise.

1. Introduction

Intermediate washer is an important part of disc assembly in automobile clutch, and the quality of cross-section will affect the assembly of disc assembly. With the higher and higher requirement for the quality of cross-section of parts from the automobile plants, fine blanking is adopted to produce intermediate washer by enterprise. Fine blanking is a method to use stamping die to cause plastic shear deformation of sheet metal[1-2]. The material of intermediate washer is C10 steel, and the thickness is 4.5 mm. The quality of cross-section of fine blanking is affected by many factors, such as blanking clearance, radius of corner of punch, blanking speed, blank holder force, counter force and tooth angle of blank holder. It is time-consuming and labor-consuming to obtain the optimized fine blanking process parameters by means of traditional die trail. With the rapid development of finite element simulation technology, Deform-2D is used to simulate the fine blanking process of intermediate washer based on orthogonal test, the influence of fine blanking process parameters on the quality of cross-section is analyzed, so as to optimize the fine blanking process parameters of intermediate washer and provide a reference for the actual production of enterprise.
2. Finite element simulation of fine blanking

2.1 Establishment of finite element model

The geometric model of fine blanking is established by Pro/E as shown in figure 1, and the process of fine blanking for intermediate washer is simulated by Deform-2D. The simulation process is divided into two steps: firstly, the tooth-shaped blank holder is pressed into the sheet; secondly, the blank holder force and counter force are applied on the tooth-shaped blank holder and the ejector plate respectively, and then punch moves downward to complete fine blanking of the sheet metal. In the simulation process of fine blanking, sheet metal is set as plastic body, punch, die, tooth-shaped blank holder and ejector plate are set as rigid body. The thickness of sheet is 4.5 mm and the material is C10 steel. The stress-strain curve of the material (as shown in figure 2) is obtained by tensile test of C10 steel with an electronic universal testing machine. The diameter of punch is \( \varnothing5.25 \) mm, blanking clearance is 0.5% \( t \) (\( t \) is the thickness of sheet metal), radius of corner of punch is R0.15 mm, radius of corner of die is R0.3 mm, the distance of the teeth is 3.6 mm, blank holder force is 450 kN, counter force is 150 kN, blanking speed is 5 mm/s\(^{-1}\), friction coefficient is set as 0.12, and fracture criterion of the material is chosen as Normalized C&L. Furthermore, the local mesh refinement technology is selected to divide the mesh of fine blanking deformation area of sheet metal.

![Figure 1. Geometric model of fine blanking](image1)

![Figure 2. Curve of stress versus strain for C10 steel](image2)

2.2 Analysis of finite element simulation results

![Figure 3. Effective stress distribution in the process of fine blanking](image3)

Figure 3 shows the distribution of effective stress during fine blanking of sheet metal. It can be seen that fine blanking deformation mainly concentrates on the narrow blanking clearance of sheet metal, and equivalent stress reaches maximum in deformation area of fine blanking. According to the simulation result, it can be seen that the maximum equivalent stress of sheet metal increases from 439 MPa to 667 MPa with the increase of punch stroke. Figure 3(a) shows the distribution of equivalent...
stress when the tooth-shaped blank holder is pressed into the metal sheet. When the tooth-shaped blank holder is pressed into the sheet metal, the sheet metal contacted with the tooth ring undergoes plastic deformation due to pressure, while other areas only occur elastic deformation, and it enhances hydrostatic stress of fine blanking deformation. Therefore, it is beneficial to the plastic deformation of sheet metal. Figure 3(d) shows the distribution of equivalent stress near the end of fine blanking, the distribution area of equivalent stress field is relatively narrow. However, the value of equivalent stress reaches the maximum with the hardening effect of material, shear cracks are more prone to occur, and it leads to the fracture separation of sheet metal.

3. Process parameters optimization of fine blanking based on orthogonal test

3.1 Design of orthogonal test
Orthogonal test is a method to analyze and optimize multi-factor and multi-level problems based on the design of orthogonal table[3-6]. In order to analyze the influence of fine blanking process parameters on the quality of cross-section for intermediate washer by means of orthogonal experiment, blanking clearance(A), radius of corner of punch(B), blanking speed(C), tooth angle of blank holder(D), blank holder force(E) and counter force(F) are selected as influencing factors, and length of shear zone is selected as evaluation index. Blanking clearance is chosen as 0.5\%t, 0.7\%t and 0.9\%t; Radius of corner of die is chosen as R0.06 mm, R0.09 mm and R0.12 mm; Blanking speed is chosen as 5 mm•s\(^{-1}\), 10 mm•s\(^{-1}\) and 15 mm•s\(^{-1}\); Blank holder force is chosen as 350 kN, 400 kN and 450 kN; Counter force is chosen as 130 kN, 140 kN and 150 kN; Tooth angle of blank holder is chosen as 30°, 45° and 60°. Therefore, orthogonal table of L18(3\(^7\)) is chosen in order to minimize the simulation times of fine blanking of intermediate washer. The simulation results are shown in table 1 by numerical simulation.

| Simulation results of fine blanking for intermediate washer | blanking clearance | radius of corner of punch | blanking speed | tooth angle of blank holder | blank holder force | counter force | length of shear zone |
|-----------------------------------------------------------|--------------------|--------------------------|----------------|-----------------------------|-------------------|--------------|--------------------|
| (mm) | (mm) | (mm•s\(^{-1}\)) | (°) | (kN) | (kN) | (mm) |
| 1 | 0.5\%t | 0.06 | 5 | 30 | 350 | 130 | 3.593 |
| 2 | 0.5\%t | 0.09 | 10 | 45 | 400 | 140 | 3.697 |
| 3 | 0.5\%t | 0.12 | 15 | 60 | 450 | 150 | 3.782 |
| 4 | 0.7\%t | 0.06 | 5 | 45 | 400 | 150 | 3.65 |
| 5 | 0.7\%t | 0.09 | 10 | 60 | 450 | 130 | 3.67 |
| 6 | 0.7\%t | 0.12 | 15 | 30 | 350 | 140 | 3.533 |
| 7 | 0.9\%t | 0.06 | 10 | 30 | 450 | 140 | 3.427 |
| 8 | 0.9\%t | 0.09 | 15 | 45 | 350 | 150 | 3.586 |
| 9 | 0.9\%t | 0.12 | 5 | 60 | 400 | 130 | 3.306 |
| 10 | 0.5\%t | 0.06 | 15 | 60 | 400 | 140 | 3.715 |
| 11 | 0.5\%t | 0.09 | 5 | 30 | 450 | 150 | 3.794 |
| 12 | 0.5\%t | 0.12 | 10 | 45 | 350 | 130 | 3.582 |
| 13 | 0.7\%t | 0.06 | 10 | 60 | 350 | 150 | 3.634 |
| 14 | 0.7\%t | 0.09 | 15 | 30 | 400 | 130 | 3.584 |
| 15 | 0.7\%t | 0.12 | 5 | 45 | 450 | 140 | 3.617 |
| 16 | 0.9\%t | 0.06 | 15 | 45 | 450 | 130 | 3.596 |
| 17 | 0.9\%t | 0.09 | 5 | 60 | 350 | 140 | 3.5 |
| 18 | 0.9\%t | 0.12 | 10 | 30 | 400 | 150 | 3.492 |

3.2 Analysis of orthogonal test results
The simulation results are analyzed by range analysis, and the analysis results are shown in table 2. 

\[ K_{ij} = \frac{1}{s} K_{ij}, \quad K_{ij} \] represents the sum of experimental results when the level number is \(i\) on the column \(j\).
s represents the number of times when the level number is \( i \) on the column \( j \); \( \bar{K}_{ij} \) represents the average value of results when the level number is \( i \) on the column \( j \); \( R_j \) represents range. According to the analysis data of table 2, it can be concluded that the influence of fine blanking process parameters on length of shear zone is as follows: blanking clearance, counter force, radius of corner of punch, blank holder force, blanking speed, tooth angle of blank holder.

### Table 2. Range analysis of simulation results for orthogonal test

| Source of variance        | Sum of squares of deviations | Freedom | \( F \) value | \( F_c \) critical value | Significance |
|---------------------------|-----------------------------|---------|---------------|--------------------------|--------------|
| blanking clearance        | 0.134                       | 2       | 67            | 19                       | *            |
| radius of corner of punch | 0.023                       | 2       | 11.5          | 19                       |              |
| blanking speed            | 0.011                       | 2       | 5.5           | 19                       |              |
| tooth angle of blank holder| 0.008                      | 2       | 4             | 19                       |              |
| blank holder force        | 0.023                       | 2       | 11.5          | 19                       |              |
| counter force             | 0.033                       | 2       | 16.5          | 19                       |              |
| Error term                |                             | 2       |               |                           |              |

The levels of each factor are taken as abscissa, and the average length of shear zone is taken as ordinate. The changing trend between factors and indexes is obtained as shown in figure 4, it can be seen that length of shear zone decreases with the increase of blanking clearance, and it shows a change trend that increases first and then decreases with the increase of radius of corner of punch and tooth angle of blank holder, while it increases with the increase of blanking speed, blank holder force and counter force.

![Figure 4. Relation chart between factors and index](image)

### Table 3. Variance analysis of simulation results for orthogonal test

| Source of variance        | Sum of squares of deviations | Freedom | \( F \) value | \( F_c \) critical value | Significance |
|---------------------------|-----------------------------|---------|---------------|--------------------------|--------------|
| blanking clearance        | 0.134                       | 2       | 67            | 19                       | *            |
| radius of corner of punch | 0.023                       | 2       | 11.5          | 19                       |              |
| blanking speed            | 0.011                       | 2       | 5.5           | 19                       |              |
| tooth angle of blank holder| 0.008                      | 2       | 4             | 19                       |              |
| blank holder force        | 0.023                       | 2       | 11.5          | 19                       |              |
| counter force             | 0.033                       | 2       | 16.5          | 19                       |              |
| Error term                |                             | 2       |               |                           |              |

Range analysis has the limitation of evaluating the impact of process parameters on the evaluation index inaccuracy. Therefore, variance analysis is carries out based on simulation results of orthogonal test in table 1, and the variance analysis results are shown in table 3. It can be seen that the blanking clearance has a significant effect on length of shear zone of fine blanking for intermediate washer.
3.3 Optimization of fine blanking process parameters
According to the data in table 1, it can be seen that the process scheme for the length of shear zone of cross-section reaches the maximum is A1B2C1D1E3F3. The simulation results show that the length of shear zone is 3.794 mm as shown in figure 5(a). However, according to figure 4, it can be seen that the optimum combination of process parameters is A1B2C3D2E3F3, that is, blanking clearance is 0.5%t, radius of corner of punch is R0.09 mm, blanking speed is 15 mm•s⁻¹, tooth angle of blank holder is 45°, blank holder force is 450 kN and counter force is 150 kN. The optimized process parameters of fine blanking are simulated by Deform-2D, and the simulation result is shown in figure 5(b), the length of shear zone is 3.945 mm.

![Simulation results of cross-section for fine blanking](image)

3.4 Experimental Verification of Optimum Scheme for Fine Blanking
In order to verify the optimization scheme of fine blanking for intermediate washer, the blanking experiment is carried out by means of stamping die, and the part of intermediate washer is shown in figure 6. In addition, Zeiss EVO18 scanning electron microscope is used to measure the length of shear zone of cross-section (as shown in figure 7). The experimental value is 3.438 mm, and the relative error between simulation value and experimental value is 12.9%. The error value is within the error range acceptable to the enterprise. The correctness and reliability of finite element simulation applied to the simulation of fine blanking process of intermediate washer is verified, and it has certain guiding significance for the die design and maintenance of similar products in enterprise.

![Part of fine blanking for intermediate washer](image)  ![Cross-section of part](image)

4. Summary
The process parameters of fine blanking of intermediate washer are optimized based on orthogonal test and simulation, and the main conclusions are obtained as follows:

1) The influence degree of process parameters on length of shear zone for fine blanking is as follows: blanking clearance, counter force, radius of corner of punch, blank holder force, blanking speed, tooth angle of blank holder. Blanking clearance has a significant effect on length of shear zone by variance analysis.
(2) The length of shear zone decreases with the increase of blanking clearance, and it increases first and then decreases with the increase of radius of corner of punch and tooth angle of blank holder, while it increases with the increase of blanking speed, blank holder force and counter force.

(3) The optimal combination of process parameters are obtained based on the analysis of orthogonal test results: blanking clearance is 0.5%, radius of corner of punch is R0.09 mm, blanking speed is 15 mm•s⁻¹, tooth angle of blank holder is 45°, blank holder force is 450 kN and counter force is 150 kN, and simulation value of length of shear zone is 3.945 mm. The experimental value of length of shear zone is 3.438 mm, and the relative error between simulation value and experimental value is 12.9%. It meets the requirement of practical production of enterprise, and it verifies the correctness and reliability of finite element simulation.

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