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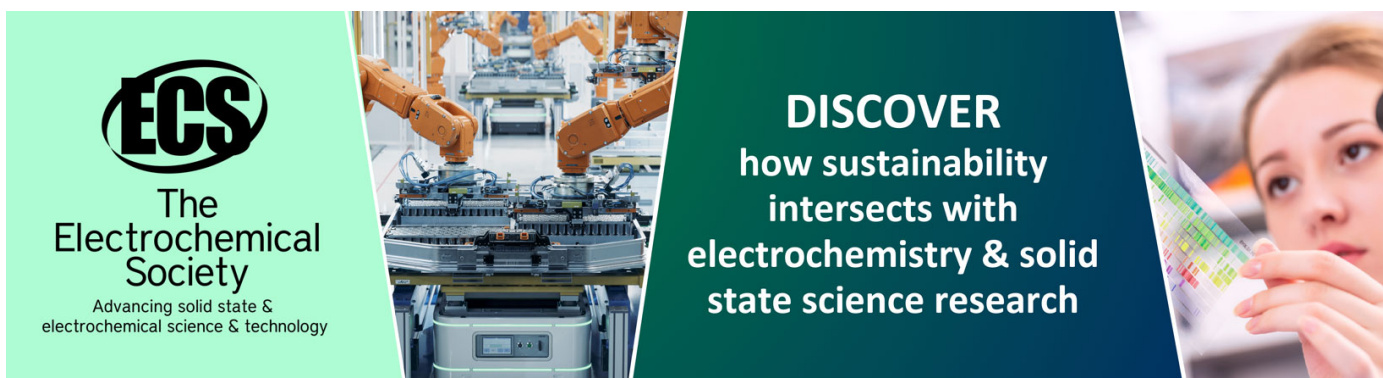
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Automobile Connecting Rod Forging Optimization Based on DEFORM and Orthogonal Experiment

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Abstract. Taking blank temperature, mould temperature and friction coefficient as test factors, the orthogonal experiment of three factors and three levels of automobile connecting rod forging was designed. Using Deform-3d, the forging experiment under different factors is simulated, and the forging results under different technological parameters were obtained. The process parameters of connecting rod forging are optimized by using the comprehensive measurement method and taking deformation uniformity and maximum forming load as indexes. The results show that the optimized process parameters can reduce the forming load and improve the deformation uniformity.

1. Foreword

Connecting rod is an important part of automobile engine, which plays an important role in converting reciprocating motion of engine piston into rotation motion of crankshaft, and bears higher impact load and stress [1]. At present, the main processing method of automobile connecting rod is forging. With the improvement of engine performance requirements, connecting rod production technology is also continuously improved, and the hot forging technology, quality and efficiency of connecting rod are required to be improved [2].

In order to improve the production quality of connecting rod forging, this paper takes the forging processing of a certain automobile connecting rod as the research objective, according to the orthogonal experiment method, designed the orthogonal experiment with three factors and three levels, including blank temperature, mold temperature and friction coefficient, and adopted Deform-3d software to conduct the forging simulation experiment simulation.

2. Establish simulation model of connecting rod forging

UG is adopted to establish the three-dimensional model of connecting rod forging blank and upper and lower moulds, which is imported into Deform-3d, and position interference adjustment is carried out to establish the simulation model of connecting rod forging, as shown in the Figure 1 simulation model of connecting rod.



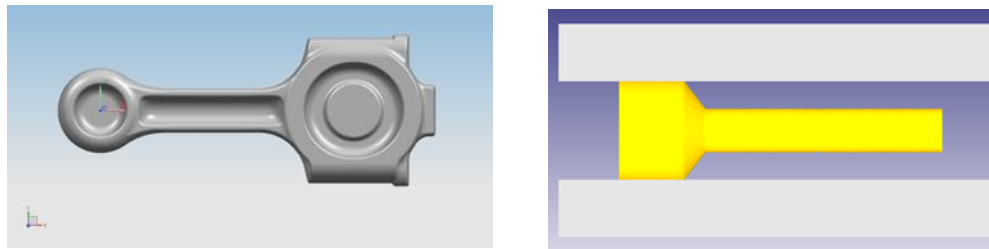


Figure 1. Simulation model of connecting rod forging.

Blank material for 1045 # steel, can be directly obtained from the Deform, the blank according to the tetrahedron grid, grid nodes is established for 12699, 11850 polyhedron unit, up and down mold movement by mechanical pressure, set up each step by step into the distance and step length, according to the experimental parameters to the blank temperature, mold temperature, the coefficient of friction gives corresponding numerical values.

3. Orthogonal experimental design

Orthogonal test design method is a method to arrange and analyse multi-factor experiments scientifically by using normalized orthogonal table. It can select representative experimental schemes from many experimental schemes, and analyse these experimental schemes to obtain the optimal production process [3]. The design process of orthogonal experiment generally includes four steps: selecting table and designing table head, defining and completing experimental program, calculating range to determine the order of primary and secondary factors, and determining the optimal program. In this paper, the orthogonal experimental design of automobile connecting rod forging is designed by taking automobile connecting rod forging process parameters as experimental factors and connecting rod forging quality optimization as experimental objective.

3.1 Design experimental factors and levels

Preheating temperature of blank is an important parameter of hot forging process. Preheating treatment of blank can improve the atomic fluidity inside metal, which is conducive to forging, but too high temperature will easily cause metal surface sintering, affecting the quality of forgings [4]. Forging process, the die and blank exposure will cause the decline of blank temperature, makes the metal blank resistance increases, is not conducive to the forging forming, at the same time die contact surface and the contact surface temperature difference, thermal stress, can lead to mould deformation, and affects the quality of the forging forming, therefore also need to analyse die preheating temperature [5]. The friction between the die and the blank will reduce the metal fluidity and the friction coefficient will directly affect the deformation uniformity. Therefore, this paper selected blank temperature, mould temperature, friction coefficient three experimental factors, and according to the actual forging process parameters, the blank temperature is set at 1100°C, 1150°C, 1200°C, mould temperature is set at 200°C, 250°C, 300°C, friction coefficient is set at 0.3, 0.35, 0.4.

The experiment of three factors and three levels was designed according to the orthogonal experiment method, and the orthogonal experiment table of $L_9 (3^4)$ was selected. The horizontal design of experimental factors was shown in Table 1.

Table 1. Factors and levels of orthogonal experiment.

	A	B	C
	Blank Temperature /°C	Mould Temperature /°C	Friction Coefficient
1	1100	200	0.40
2	1150	250	0.35
3	1200	300	0.30

Orthogonal experiment has three factors and three levels. As shown in the Table 2, the orthogonal table of $L_9 (3^4)$ is adopted. Meanwhile, in order to analyze the variance of orthogonal experiment, an empty column is added to the head design [6].

Table 2. Design of gauge head for connecting rod forging experiment.

Factor	A	B	C	Vacant Column
Number	1	2	3	4

3.2 Determine the experimental indexes

In the process of connecting rod forging, the better the deformation uniformity of the forgings, the lower the internal stress of the forgings, and the higher the performance and quality of the forgings. The equivalent strain is an important basis for measuring the deformation uniformity. In this paper, the maximum equivalent strain and minimum equivalent strain difference are selected as the indexes to measure the uniformity of forging deformation. Considering the influence of forming load on the service life of die in forging process, this paper takes the maximum forming load in forging process as the index to measure the service life of die.

3.3 Experimental scheme

According to the orthogonal table of $L_9 (3^4)$, 9 groups of experiments with different factor levels were set up. Forging simulation is carried out according to different factor levels of each group, and the simulation results of one group of experiments are shown in Figure 2. According to the experimental indexes, the forming load and equivalent strain obtained by each group of experiments are derived, and the data are analysed.

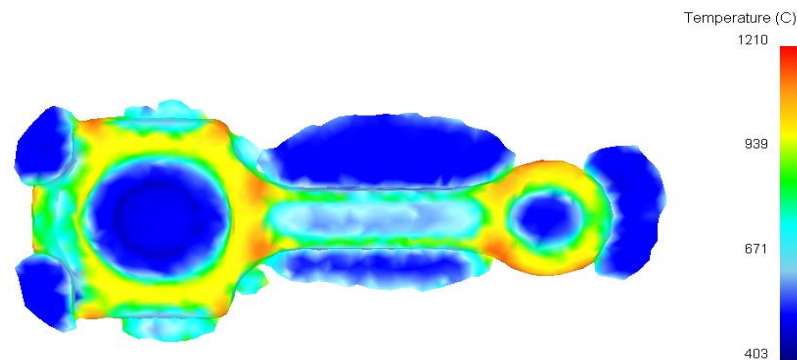


Figure 2. Simulation results.

4. Results analysis and optimization

4.1 Orthogonal experimental results

Data required by each group of experiments were extracted, and Table 3 orthogonal experimental data table was obtained.

Table 3. Orthogonal experimental data sheets.

Number	Blank Temperature /°C	Mould Temperature /°C	Coefficient of Friction	Vacant Column	Forming Load / $\times 10^6 N$	Equivalent Strain Difference
	1	2	3	4		
1	1200	200	0.40	1	10.3	4.216
2	1200	250	0.35	2	9.8	4.320
3	1200	300	0.30	3	9.3	4.490
4	1150	200	0.35	3	10.3	4.194
5	1150	250	0.30	1	10.9	4.481
6	1150	300	0.40	2	10.2	4.511
7	1100	200	0.30	2	11.6	4.407
8	1100	250	0.40	3	12.3	4.394
9	1100	300	0.35	1	11.3	4.290

4.2 Forging parameter analysis based on forming load

Taking forming load as optimization parameter, the range analysis of orthogonal experimental table is carried out, as shown in Table 4 Analysis of forming load range.

Table 4. Analysis of forming load range.

Sum	Blank Temperature	Mould Temperature	Coefficient of Friction	Vacant Column
T_{1j}	29.4	32.2	32.8	32.5
T_{2j}	31.4	33.0	31.4	31.6
T_{3j}	35.2	30.8	31.8	31.9
R_j	5.8	2.2	1.4	0.9

The range analysis shows that the blank temperature has a great influence on the forming load. In this experiment, the selected temperature is 1200°C, followed by mould temperature and friction coefficient, respectively 300°C and 0.35 °C. The combination of these parameters did not appear in the orthogonal experiment. The experimental design was carried out for these parameters, and the experimental results were compared with the third experiment with the smallest forming load. As shown in FIG. 3-1 load formation curve, the experimental results show that when the blank temperature, mould temperature and friction coefficients are 1200°C, 300°C and 0.35 respectively, the forming load in the forging process decreases somewhat, and the maximum forming load is $8.9 \times 10^6 N$.

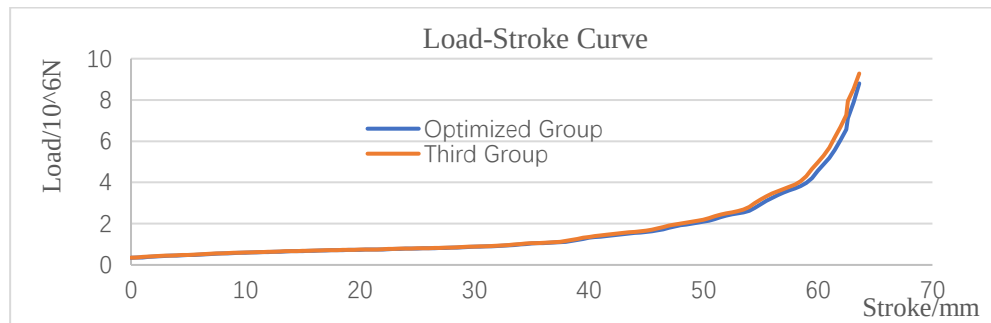


Figure 3. Load stroke curve

4.3 Forging parameter analysis based on equivalent strain difference

Taking the equivalent strain difference as the optimization target, the range analysis of forging parameters is carried out, and the range analysis of the equivalent strain difference in table 5 is obtained. From range analysis, it can be known that the minimum equivalent strain difference can be obtained. The blank temperature should be 1200°C, the mould temperature 200°C, and the friction coefficient 0.35.

Table 5. Equivalent strain difference

Sum	Blank Temperature	Mould Temperature	Coefficient of Friction	Vacant Column
T_{1j}	13.025	13.113	13.121	12.988
T_{2j}	13.398	13.195	12.804	13.237
T_{3j}	13.092	13.290	13.398	13.078
R_j	0.306	0.177	0.594	0.249

Experimental results are shown in Figure 4 strain optimization results, with the maximum strain of 4.22, the minimum strain of 0.217 and the strain difference of 4.003. By comparing the strain difference of 4.194 in the fourth group of the optimal results in the orthogonal experimental table, the feasibility of the optimization results is proved.

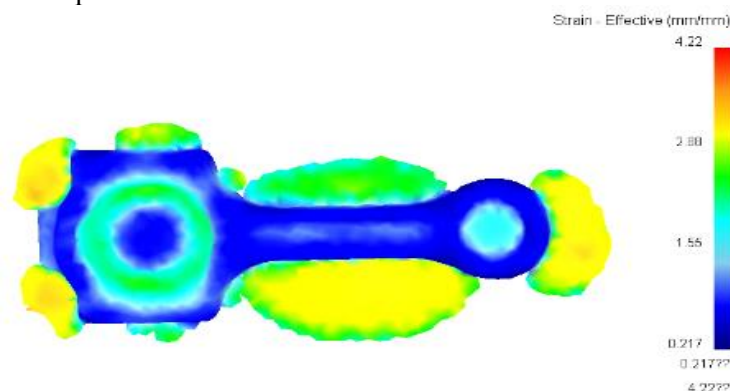


Figure 4. Strain optimization results

4.4 Multi-index analysis based on comprehensive balance method

In the orthogonal experiment with multiple indicators, the combination of factors and parameters corresponding to each indicator may be inconsistent. In the comprehensive analysis, the comprehensive

balance method needs to be considered. According to the orthogonal experimental results, the trend chart of experimental factors and indicators is drawn, and the results are shown in Figure 5. Trend chart of factor indicators.

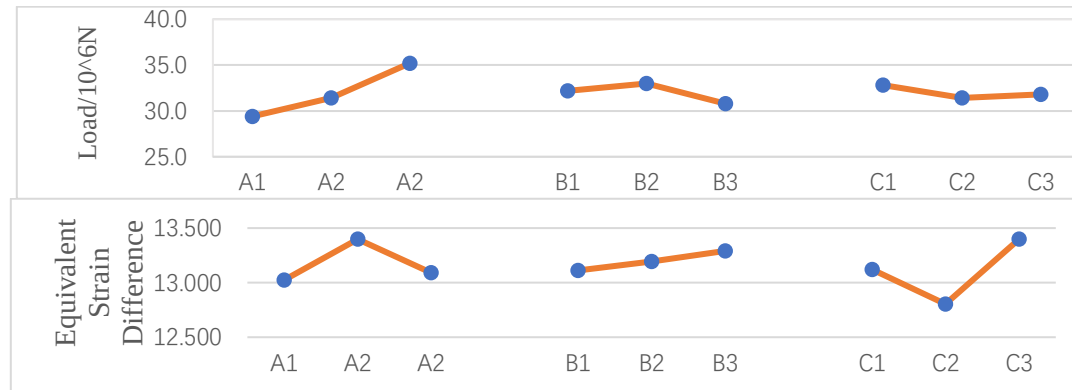


Figure 5. Trend chart of factor indicators

As can be seen from the trend chart of factor indicators, when the forming load and equivalent strain difference are the minimum values, the corresponding blank temperature and friction coefficient are 1200°C and 0.35 °C, and the corresponding mold temperature is 300°C and 200°C. It can be seen from range analysis that, among the three factors, mold temperature has the smallest influence on the equivalent strain difference, and the influence on the maximum forming load is between blank temperature and friction coefficient, so mold temperature should be based on the maximum forming load and choose 300°C.

5. Conclusion

The blank temperature, mould temperature and friction coefficient were optimized through the three factors and three levels orthogonal experiment. The results show that the blank temperature has the greatest influence on the maximum forming load. The friction coefficient had the greatest influence on forging deformation uniformity. When the blank temperature, mold temperature and friction coefficient were taken as 1200°C, 300°C and 0.35 °C respectively, the maximum forming load in the forging process was the smallest and the deformation uniformity was better.

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