Virtual Simulation Stamping Forming Analysis and Experiment of Battery Pack Top Cover

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Abstract: In view of the manufacturing process defects existing in sheet metal stamping forming of battery pack top cover, this paper carries out numerical simulation on top cover stamping forming based on simulation software, analyzes the specific influencing factors of the forming process, and designs an orthogonal experiment scheme, with the maximum thinning rate as the evaluation index. The primary and secondary relationship of the influence of the factors on the evaluation index was obtained and the optimal process parameters (i.e., stamping speed 1000mm/s, blank holder force 80T, friction coefficient 0.12, concave and convex die clearance 1.26mm) were obtained. Under the guidance of the optimal parameters, it was found that the maximum thinning rate and maximum thick-increasing rate under the simulation were close to the actual stamping value, and the error of the maximum thinning rate was 8.9% and the error of the maximum thick-increasing rate was 7.5%, which were reasonable.

Keywords: Battery pack; Top cover; stamping; Orthogonal test;Virtual simulation
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1 INTRODUCTION

One of the most important core components of electric vehicles was battery pack, and the performance of battery pack affects the driving range of the vehicle [10],[11],[13] The energy of battery pack was not only affected by the battery performance itself, but also the weight of battery pack shell was an important factor affecting the driving range of electric vehicles. In order to improve the overall performance of battery pack, the energy density was directly affected by the weight reduction of battery pack structure. The lightweight of battery packs was mainly focused on the structural parts, including the top cover, tray and support structure parts, but the lightweight effect on the top cover and tray was particularly prominent. The main function of the top cover was to close the battery pack, and it was the largest battery pack component. Improving top cover weight will help reduce the overall quality of the battery. Although some manufacturers in the top cover design of carbon fiber material, but its cost was high. Compared with carbon fiber top cover, in addition to cost, its process complexity was higher than sheet metal material, and the weight of cast carbon fiber plastic steel was higher than that of thin sheet metal [13]. The production output of thin sheet metal formed by stamping was higher than that of plastic steel made of fiber material. Its cost would be reduced in the process of batch manufacturing, and its manufacturing was more in line with the needs of the automobile industry.

Stamping forming was a method of using concave and convex die to apply up and down extrusion pressure on the sheet metal, which was deformed on the die. Elastic-plastic deformation occurs in the process of forming and extrusion, which may lead to scratches, wrinkles, cracks and other technological and quality defects of sheet metal. So, battery pack top cover was Choose appropriate stamping process parameters, which can effectively solve this problem to a certain extent [15]. combining the modern simulation technology and experimental way, the manufacturing process optimization of the top cover was deeply studied, and the actual production was guided according to the process parameters optimization conclusion. Virtual simulation technology is employed to enhance the analysis and visualization of the stamping forming process, enabling a more comprehensive understanding of material deformation and defect formation.

2 STRUCTURAL RELATIONSHIP OF THE TOP COVER

The battery pack structure was mainly composed of top cover, module support and tray, as shown in Figure 1.The whole battery modules were supported by the tray; modules were fixed on the tray by the module bracket, and the battery pack was sealed by the top cover. The top cover was designed with textured stiffeners and which were aimed to enhance mechanical strength due to the large tensile area leads to excessive stress.

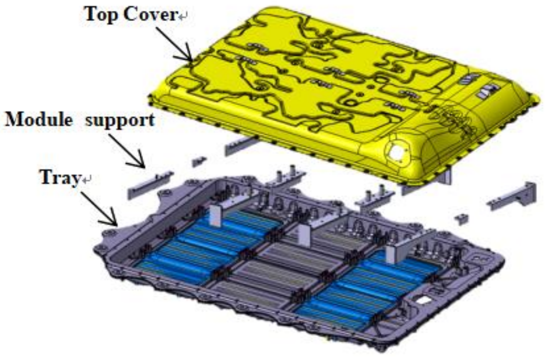

Figure 1: Structural relationships.

3 ESTABLISHMENT OF TOP COVER STAMPING SIMULATION MODEL

Due to the complex design of the cover reinforcement part of the top cover model, it was difficult to judge whether there would be cracks, wrinkles, scratches and other manufacturing problems in the process of stamping just by relying on years of stamping experience [14],[15].With the development of computer technology, with the help of advanced computer simulation technology to evaluate the manufacturing process would be the mainstream, each simulation result was equivalent to a mold repair work, effectively reduced the workload of engineers, but also improved the manufacturing efficiency. Influencing factors of sheet metal stamping process were analyzed through AUTOFORM R2 simulation software. Therefore, the top cover stamping process parameters should not be correctly selected. This paper would combine theoretical analysis and the use of finite element analysis tools to solve the above problems.

The stamping shape of the top cover was relatively complex, which had the characteristics of curved shape, drawing and expansion. Three areas were analyzed: Area ⅰ was curved deformation; Area ⅱ was deep drawing, the material was radial tension, the lower edge of the side wall had a thinning trend; The lateral wall of area ⅲ was thinner and the plane thickened due to the radial tension. The whole process of top cover from blanking to mechanical plastic, deep shaping was the most important process. In the actual production, the maximum thinning rate of the forming parts should be less than 20%, the maximum thickening rate should be less than 10%, no cracks, scratches, wrinkles and other phenomena.

CATIA software is a software with rich modeling functions. The 3D model of top cover is established, as shown in Figure 2.The thickness of top cover is 1.2mm (1.0t), and the length, width and height were 1552mm ×1132mm ×144mm. The material properties were 5754 aluminum series, as shown in specific material property parameters Table 1. In addition, corresponding models of concave and convex die and blank holder should also be established when the simulation software was introduced for analysis. According to the requirements of simulation calculation efficiency, a pre-treatment model of the top cover should be established, and the finite element mesh should be divided, and the calculation accuracy and efficiency should be balanced [4],[8],[9],[12].

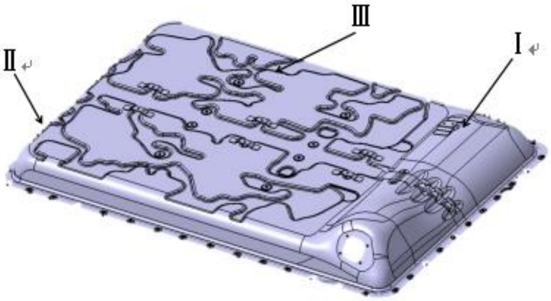

Figure 2: 3D modeling of the top cover.

parameter	*Modulus of elasticity/ gpa*	*Poisson's ratio*	*The yield strength /mpa*	*Tensile strength/MPa*	*Hardening index*	*Thickness anisotropy index r_0, r_{45}, r_{90}*	*Density (g/cm3)*
Number of values	*70*	*0.3*	*98.3*	*227.2*	*0.27*	*0.65/0.68/0.63*	*2.79*

Table 1: Mechanical property parameters of 5754 series materials.

4 THE INFLUENCE OF DIFFERENT PROCESS PARAMETERS ON THE TOP COVER FORMING

4.1 Influence of Blank Holder Force on Deep Drawing Forming

The blank holder force was generally calculated using the empirical formula [7]:

$$F = Q \cdot A \tag{1}$$

Where: F is blank -hold force (unit: KN); Q is the blank holder force per unit area, generally 2-4.5Mpa, the unit is MPa; A is the projected area of sheet material under the blank holder ring range, in mm2. After measurement, the sheet material projection area under the blank holder ring is 182840mm2, and the blank holder force of deep drawing is converted to 365.680kN-822.780kN.
The role of blank holder force in deep drawing forming process is very important, too large or too small blank holder force will have a relatively large impact on the wrinkling and cracking of the top, so the selection of appropriate blank holder force is very critical [1],[3],[5]. In the simulation experiment, the blank holder force was set as 500KN, 700KN and 900KN, the stamping speed was set as 1500mm/s, the friction coefficient was 0.12 and the clearance of the concave and convex die was 1.26mm. The simulation results are shown in Table 2. According to the analysis in Table 2, the value of blank holder force increases continuously, which has a certain effect on the maximum thinning rate. When the blank holder force increases uniformly, the maximum thinning rate increases obviously, and the maximum thickening rate decreases. When the blank holder force is 90T, the maximum thinning rate is higher, and and there is a risk of cracking of the top cover due to thinning.

Blank holder force (KN)	*Maximum thinning rate /%*	*Maximum thickening rate /%*
500	*13.92*	*9.63*
700	*14.89*	*8.22*
900	*19.43*	*6.67*

Table 2: The thinning rate and thickening rate of the top cover under different blank holder forces.

4.2 Influence of Stamping Speed on Deep Drawing Forming

The stamping speed has a great influence on the deep drawing forming to a certain extent. In AUTOFORM software, different values of stamping speed are set under certain blank holder force, and the influence of stamping speed factors on the thinning rate is analyzed. According to the reference [9][1], in the stamping simulation, the stamping speed is generally 1000mm/s-5000mm/s. In the simulation experiment, the stamping speed is set as 1500mm/s, 2500mm/s and 3500mm/s, respectively. The blank holder force with a fixed value is 600KN, and the clearance and friction coefficient of concave and convex die are unchanged. The simulation data are shown in Table 3 below. According to the analysis in the data table, the increase of the stamping speed has an impact on the thinning rate and the thickening rate, and the maximum thinning rate and the maximum thickening rate both have an increasing trend. In the process of increasing the stamping speed, the maximum thinning rate reaches 25.03%, and cracks appear in the sheet.

Stamping Speed（mm/s）	*Maximum thinning rate /%*	*Maximum thickening rate /%*
1500	*14.02*	*9.13*
2500	*15.94*	*9.35*
3500	*25.03*	*9.47*

Table 3: The thinning rate and thickening rate of the top cover at different stamping speeds.

4.3 Orthogonal Experiment to Optimize Process Parameters

Orthogonal experiment is a method to study the level of multiple factors, which can be divided into comprehensive experimental method and simple experimental method. In this paper, single-index orthogonal simple experimental method will be used to design the influence of punching pressure, blank holder force and other factors on the process, and the primary and secondary relationship of the influence of each factor on the experimental index will be obtained through range analysis method [9],[7],[6]. Taking the thinning rate as the experimental objective, blank holder force, punching pressure, friction coefficient, concave and convex die clearance are selected as input factors, and the factor levels are shown in Table 4. A single index orthogonal experiment was used to design 9 groups of experiments with 4 factors and 3 levels of orthogonal experiment scheme, as shown in Table 5. The change of experimental factors is bound to affect the final result, usually by using the extreme difference analysis. In orthogonal experiments, the range value can reflect the direct influence of factors on experimental indexes. This paper finds out the primary and secondary relationship of factor levels affecting a single index through the range analysis of factors at different levels. The experimental results are shown in Table 5. According to the extreme difference analysis in table 5, the influence relationship of factors on a single experimental index is as follows: ①stamping Speed;②blank holder force;③concave and convex die clearance; ④coefficient of friction. In this paper, the single experimental index is the thinning rate, and the optimal maximum thinning rate is found through the optimization of the experimental scheme. Through nine orthogonal experiments, the optimal forming process parameters are A1B3C2D1 (stamping speed 1000mm/s, blank holder force 800KN, friction coefficient 0.12, concave and convex die clearance 1.26mm).

Level	*experimental factors*			
	A stamping speed（mm/s）	*B blank holder force（KN）*	*C friction coefficient*	*D concave and convex die clearance（mm）*
1	*1000*	*600*	*0.08*	*1.26（1.05t）*
2	*2000*	*700*	*0.125*	*1.32(1.1t)*
3	*3000*	*800*	*0.16*	*1.38(1.15t)*

Table 4: Factors of orthogonal experiment.

Note: Ⅰj、Ⅱj、Ⅲj are the sum of the maximum thinning rates corresponding to levels 1, 2, and 3；j=A, B, C, D; Ⅰ-j、Ⅱ-j、Ⅲare the average values of the sum of the maximum thinning rates corresponding to levels 1, 2 and 3; Rj is the extreme difference of the j- th factor, Rj=max (Ⅰ-j, Ⅱ-j, Ⅲ-j)-min (Ⅰ-j, Ⅱ-j, Ⅲ-j)

No.	A stamping speed/（mm/s）	B blank holder force/（KN）	C friction coefficient	D concave and convex die clearance (mm)	Maximum thinning rate/%	Maximum thickening rate/%
1	1000（A1）	600(B1)	0.08（C1）	1.26(D1)	14.68	9.87
2	1000（A1）	700(B2)	0.12（C2）	1.32(D2)	15.32	8.13
3	1000（A1）	800(B3)	0.16（C3）	1.38(D3)	15.47	7.82
4	2000（A2）	600(B1)	0.12（C2）	1.38(D3)	15.43	9.03
5	2000（A2）	700(B2)	0.16（C3）	1.26(D1)	16.63	8.91
6	2000（A2）	800(B3)	0.08（C1）	1.32(D2)	16.01	8.03
7	3000（A3）	600(B1)	0.16（C3）	1.32 (D2)	16.42	9.17
8	3000（A3）	700(B2)	0.08（C1）	1.38 (D3)	17.62	8.68
9	3000（A3）	800(B3)	0.12（C2）	1.26 (D1)	15.02	9.92
I_j	45.47	46.53	48.30	46.33		
II_j	48.07	49.57	45.78	47.75		
III_j	49.06	46.50	48.52	48.52		
I_{-j}	15.16	15.51	16.10	15.44		
II_{-j}	16.02	16.52	15.26	15.92		
III_{-j}	16.35	15.50	16.17	16.17		
R_j	1.20	1.02	0.92	0.73		
Primary and secondary relations：A>B>C>D						
The best solution：A1B3C2D1						

Table 5: Comparison of orthogonal experimental scheme and optimization results.

5 SIMULATION AND EXPERIMENTAL VERIFICATION OF OPTIMAL PARAMETERS

Under the guidance of the optimal process parameters, the simulation shows that the maximum thinning rate of the top cover is about 15.7% and the thickening rate is about 9.3%, which meet the technological requirements of the top cover forming. The simulation thinning cloud diagram is shown in Figure 3. According to the analysis and simulation optimization results, the stamping experiment is carried out. The blank material of aluminum alloy sheet before stamping is shown in Figure 4-a, and the stamping die bed is shown in Figure 4-b. After stamping, no process quality problems were found on the top cover, as shown in Figure 5. The measured maximum thinning rate and maximum thickening rate of the formed lid are 14.3% and 8.6% respectively. Compared with the experimental results, the error value of the maximum thinning rate is 8.9%, and the error value of the maximum thickening rate is 7.5%. The simulation value is relatively close to the actual value, which meets the requirements of the top cover forming.

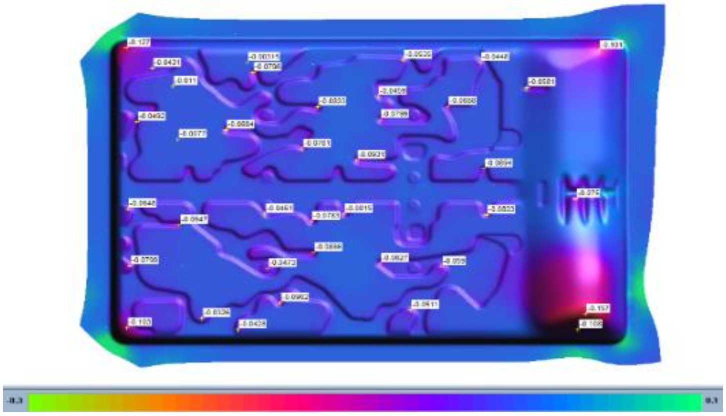

Figure 3: Cloud image of thinning rate.

(a) Blank material before stamping.

(b) Stamping die bed.

Figure 4: Blank material and stamping die bed.

Figure 5: Real picture of the top cover.

6 CONCLUSIONS

1) The AUTOFORM simulation preprocessing model was established, and the influences of stamping speed and blank holder force on the sheet metal forming of the top cover were studied. The results showed that the blank holder force and stamping speed had a great influence on the thinning rate.
2) Orthogonal experiment simple experiment method was used to analyze the factors affecting the top cover sheet metal stamping forming, and the comprehensive range method was used to analyze the influence of each factor on the experimental index, and obtained the primary and secondary relationship of the influencing factors of the maximum thinning rate. In the case of the optimal maximum thinning rate, the best process parameters were obtained, namely A stamping speed of 1000mm/s, B blank holder force of 80T, C friction coefficient of 0.12, D concave and convex die clearance of 1.26mm.
3) According to the comparison of simulation results and experimental values, it was found that the two values are relatively close in numerical value, which verifies the accuracy of simulation, and provides a useful reference for the optimization of stamping process parameters and production practice.

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