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Cracking analysis and optimization of stamping forming of rear longitudinal extension beam based on CAE

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ABSTRACT. *In this paper, the stamping forming of the rear longitudinal extension beam is taken as the research object. In view of the product cracking caused by the original forming process scheme, a pre forming process is proposed to solve this problem. The forming process is simulated by AutoForm software. Then, taking the bending angle of the product surface, the gap between the concave and convex dies, the friction coefficient, force and punch speed of the blank holder used as independent variables, as well as the maximum forming interval pull rate and maximum rebound after trimming as the objective function, the orthogonal test is designed to simulate the combination of the parameters, and then the grey correlation analysis is run to calculate the maximum thinning rate and the maximum springback of each group of test process parameters The grey correlation coefficient and correlation degree of the two targets. The optimal combination of process parameters is that the bending angle of the product surface is 60 °, the gap between the concave and convex dies is 0.2m m, the friction coefficient is 0.15, the blank holder force is 800KN, and the stamping speed is 2000 (mm/s). Using the optimized process parameters to simulate again, the simulation results show that the maximum thinning rate of the product is 12.5%. Using the forming process proposed in this paper, the actual trial production place has a good forming and qualified rear longitudinal extension beam.*

KEYWORDS: *High strength steel, Multi-objective optimization, Stamping, Grey correlation, Orthogonal test*

1. Introduction

In recent years, people have become more and more demanding on the performance of automobiles, which not only requires novel and unique appearance, but also requires lighter body and lighter fuel consumption. On the other hand, from the perspective of increasingly strict environmental protection requirements and vehicle safety, lightweighting of high-strength steel is also one of the current development directions of the automotive industry. Using high-strength steel to produce body parts can not only reduce the overall body mass, but also meet the vehicle's safety performance requirements. However, because the strength of high-strength steel has increased significantly, the difficulty of forming has also increased a lot, especially in some areas with large deformation variables, which are more prone to cracking. Finding out the root cause and solution of the problem, so as to meet the requirements of mass production, has always been an important and difficult problem in the field of stamping.

There are many factors that affect the final result of the product during the stamping process. If only by experience and simple surface phenomenon analysis, the root cause of the problem cannot be known. This article takes the rear longitudinal extension beam of a vehicle as the research object to solve the cracking of the flange transition vertical surface during the forming process, and comprehensively considers the geometric parameters of the mold and the forming process parameters. The finite element analysis software Autoform was used to analyze the possible influencing factors, combined with the orthogonal test method and gray correlation, the product was optimized by adjusting different parameters, and finally the optimal process parameters were obtained.

2. Process Analysis of the Rear Longitudinal Extension Beam and Original Process Plan

2.1 Process Analysis of Rear Longitudinal Extension Beam

The rear longitudinal extension beam is a typical support structure in automobile parts, and the digital model in CATIA is shown in Figure 1. This part plays a role in supporting the body quality in the body. The side of the part is perpendicular to the flange. In a small area, two mutually perpendicular shapes must be achieved.

ISSN 2616-7433 Vol. 2, Issue 8: 17-22, DOI: 10.25236/FSST.2020.020804

Therefore, the flange transition vertical surface is prone to cracking and high strength. The difficulty of deformation of steel materials greatly increases the risk of cracking.

2.2 Original Process Plan

The initially set process plan is divided into four sequential forming: blanking-forming-flanging shaping-punching. According to the literature and production experience, the blank holding force is set to 1000 KN and the punching speed is 2400 (mm / s). Using this scheme for trial production, it was found that the product cracked at the vertical plane of the flange transition, as shown in Figure 2. When dealing with cracking problems, I tried to change the blank holding force and punching speed, but still failed to get a qualified product

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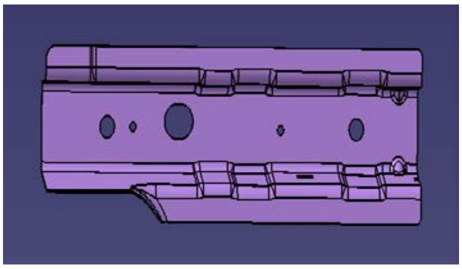

Fig.1 Product digital model

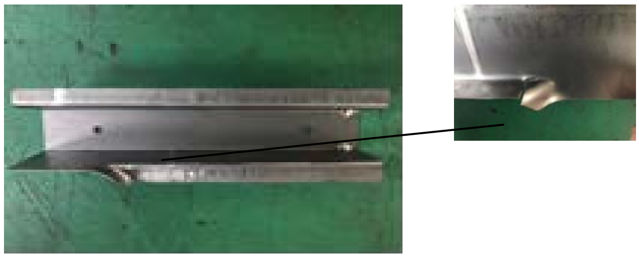

Fig. 2 Product cracking

1.3 Analysis of the original process plan

In order to find the root cause of the problems in the above-mentioned production, the numerical simulation software Autoform was used to analyze the full process stamping of the rear longitudinally extending beam. Based on the upper mold surface of the product's digital model, a single layer was extracted and imported into the Autoform software. Create the entire process according to the original process plan, and complete a specific definition for each process. The material is selected from Baosteel's QP980 with a thickness of 1.4mm. The finite element model of the forming process is shown in Figure 3. The enhanced model is a Swift / Hockett-Sherb hybrid model, and the yield model uses the Hill model.

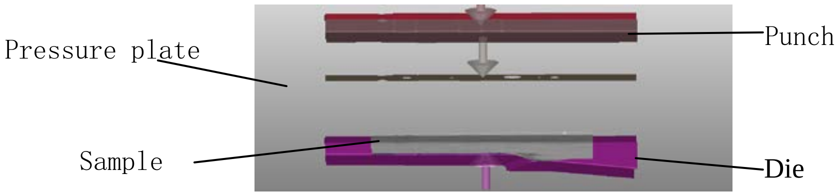

Fig. 3 Forming finite element model

The simulation results of the process plan showed that the vertical transition of the flange transition of the part cracked. According to the simulation, the product forming diagram, thinning rate diagram, and forming limit diagram (FLD) are shown in Figure 4, Figure 5, and Figure 6, respectively. From Figure 5, we can see the distribution of the overall thinning rate of the part. The maximum thinning rate is 24.2% of the flange transition vertical plane. There is a risk of cracking, and the formability of the remaining parts is good. This is the same as the cracking area in actual production. Basically match. According to production experience, the simulation results in the software can only be used as reference objects. In actual production, due to the influence of many uncontrollable factors such as old equipment and personnel operations, coupled with the high yield and tensile strength of the high strength steel itself, Therefore, the flange transition vertical plane is extremely prone to cracking. Most of the product cracking problems are caused by excessive main strain force. Therefore, the method of reducing the flow resistance can be considered to solve the cracking of the flange transition vertical surface. In view of this situation, the preliminary consideration is to enhance the fluidity of the material, and cooperate with the four factors of blank holding force, stamping speed, embossing die clearance, and friction coefficient to improve the stability of the stamping process and ensure product quality.

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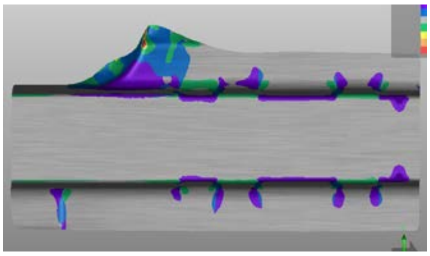

Fig.4 Product forming chart

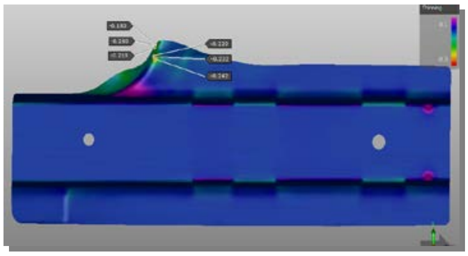

Fig.5 Thinning rate

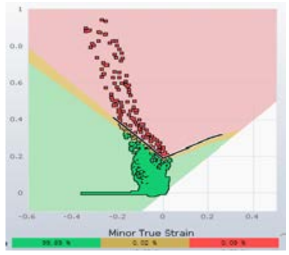

Fig. 6 FLD diagram

3. Optimization of the Process Plan

In the process of sheet metal stamping, the frictional force flowing in the vertical direction is relatively large, and it is easy to cause the risk of transitional thinning or even cracking at the corners. Therefore, this paper proposes a new process, which is to increase the preforming process and enhance the flow of the sheet. Therefore, the new process plan is: blanking-preforming-forming-flanging shaping-punching. The preforming process step is to bend the product surface at a certain angle to enhance the fluidity of the sheet in the subsequent processes. In order to obtain the optimal bending angle, the preforming bending angle is used as a variable to simulate and analyze the preforming process at different angles. . Combining the geometric parameters of the mold with the forming process parameters, the optimal process plan is finally obtained.

3.1 Design and Simulation Results of Orthogonal Experiments

Orthogonal experiments were used to optimize the parameters of the forming process by multi-objective optimization. The punching speed (E), blank holder force (D), friction coefficient (C), uneven die clearance (B), product surface bending angle (A), five were selected. For each factor, four levels are selected as shown in Table 1. If only increasing the gap of the concave-convex die and reducing the coefficient of friction, although the material flow can be improved, it will also cause problems such as subsequent rebound and insufficient deep drawing. Therefore, comprehensively considering the use of the maximum springback amount and the maximum thinning rate of the forming function, an orthogonal table L16 (45) with 5 factors and 4 levels was used to simulate the finite element values 16 times, and the results shown in Table 2 were finally obtained.

Table 1 Orthogonal Test Factors and Levels

Level	Factor				
	A/(°)	*B*/(mm)	*C*	*D*/(KN)	*E*/(mm/s)
1	20	0.1	0.13	800	2000
2	30	0.2	0.14	900	2200
3	45	0.3	0.15	1000	2400
4	60	0.4	0.16	1100	2600

Table 2 Orthogonal Test Scheme and Results

Serial number	*A*/(°)	*B*/(mm)	*C*	*D*/(KN)	*E*/(mm/s)	Forming maximum reduction rate/(%)	Maximum rebound after trimming/(mm)
1	20	0.1	0.13	800	2000	15.7	1.525
2	20	0.2	0.14	900	2200	17.4	2.865
3	20	0.3	0.15	1000	2400	15.3	2.976
4	20	0.4	0.16	1100	2600	23.2	3.954
5	30	0.1	0.14	1000	2600	16.3	1.683
6	30	0.2	0.13	1100	2400	17.7	2.642
7	30	0.3	0.16	800	2200	21	3.012
8	30	0.4	0.15	900	2000	14.2	3.296
9	45	0.1	0.15	1100	2200	18.7	2.336

10	45	0.2	0.16	1000	2000	17.3	3.314
11	45	0.3	0.13	900	2600	22.5	1.362
12	45	0.4	0.14	800	2400	19.4	2.571
13	60	0.1	0.16	900	2400	16.5	1.554
14	60	0.2	0.15	800	2600	12.7	2.765
15	60	0.3	0.14	1100	2000	18.6	1.623
16	60	0.4	0.13	1000	2200	17.8	3.164

3.2 Multi-Objective Optimization with Grey Relation

From the relevant knowledge of the gray system theory, the correlation coefficient between the process parameters and each single factor is first calculated, then the correlation coefficient is weighted, and finally the correlation degree of the objective function is obtained. The optimal process parameter is the maximum correlation. Let the reference vector sequence X_0 = {X_0 (k), k = 1, 2, ..., n}, n is the number of reference vectors, and the target vector sequence X i = {X i (k), k = 1, 2, ... , M}, m is the number of target vectors. Then the gray correlation coefficient of X_i for X_0 at the k-th point is:

$$\xi[x_i(k), x_0(k)] =$$

$$\frac{\min\limits_{i}\min\limits_{k} | x_i(k) - x_0(k) | + p \max\limits_{i}\max\limits_{k} | x_i(k) - x_0(k) |}{| x_i(k) - x_0(k) | + p \max\limits_{i}\max\limits_{k} | x_i(k) - x_0(k) |} \tag{1}$$

In the formula:ρis the resolution coefficient, usually ρ= 0.

The correlation between the reference vector sequence X 0 and the target vector sequence X i is:

$$(x_i, x_0) = \frac{1}{n}\sum_{k=1}^{n} \lambda_k \xi[x_i(k), x_0(k)] \tag{2}$$

Where: λ_k is the weight.

Pick out the minimum value of the maximum rebound amount and the maximum thinning rate from Table 2. The selected data is used as the original basic data, that is, Y_0 = {12.7, 1.362}. Then the selected maximum thinning rate value and maximum springback value are brought into equation (1), and the grey correlation coefficientsξ_1 andξ_2 of the objective function are calculated, as shown in Table 3. Because the most important problem in product forming is product cracking, the maximum thinning rate for forming is weighted by 0.8, and the maximum springback amount is weighted by 0.2. The correlation degree of the objective function can be calculated by formula (2), and the calculation result is shown in Table 3 below.

Table 3 Grey Correlation And Grey Correlation Coefficient Degree of Objective Function

Serial number	ξ_1	ξ_2	Correlation γ
1	0.286	0.063	0.687
2	0.448	0.580	0.515
3	0.248	0.623	0.624
4	1.000	1.000	0.333
5	0.343	0.124	0.635
6	0.476	0.494	0.510
7	0.790	0.637	0.398
8	0.143	0.746	0.702
9	0.571	0.376	0.488
10	0.438	0.753	0.506
11	0.933	0.000	0.479
12	0.638	0.466	0.455
13	0.362	0.074	0.638
14	0.000	0.541	0.896
15	0.562	0.101	0.543
16	0.486	0.695	0.489

ISSN 2616-7433 Vol. 2, Issue 8: 17-22, DOI: 10.25236/FSST.2020.020804

The average correlation degree of each forming process parameter is shown in Table 4. Analysis of the average correlation degree of Table 4 shows that the combination of process parameters with the largest gray correlation is: $A_4 B_2 C_3 D_1 E_1$ The combination $A_4 B_2 C_3 D_1 E_4$ test was done, so the process parameter combination obtained by the gray correlation, that is, $A_4 B_2 C_3 D_1 E_1$ was subjected to Autoform analysis. The results obtained are the same as those in the orthogonal test A The results of the $A_4 B_2 C_3 D_1 E_4$ combination were compared, and it was found that the formability of the $A_4 B_2 C_3 D_1 E_1$ combination was better. That is, the bending angle of the product surface is 60 °, the clearance of the concave-convex die is 0.2mm, the friction coefficient is 0.15, the blank holding force is 800KN, and the punching speed is 2000 (mm / s).

Table 4 Average Correlation Between the Objective Function and Each Forming Process Parameter

Level	Factors				
	A/(°)	*B*/(mm)	*C*	*D*/(KN)	*E*/(m/s)
1	0.5397	0.6119	0.5414	0.6089	0.6096
2	0.5614	0.6268	0.5369	0.5836	0.4724
3	0.4819	0.5111	0.6775	0.5637	0.5569
4	0.6417	0.4951	0.4689	0.4686	0.5858

4. Simulation Verification

The optimal process parameter combination was simulated again in Autoform software. It can be seen from the optimization results, the optimized product surface has better formability without cracking, and the maximum thinning rate of the flange transition vertical surface is 12.5%, which has been greatly improved compared to before, so the optimized process parameters It can be used as a satisfactory multi-objective optimization solution.

5. .Tryout Verification

In the subsequent process design, the optimal multi-objective parameters are used as a guide to further compensate the springback amount of the die surface, and finally control the springback amount of the die surface to ±1mm. After that, the structural part of the mold is designed, programmed, milled, tested and adjusted. Figure 7 is the lower mold in the preforming process, and Figure 8 is the finished product drawing. It can be seen that the part is well formed, the quality fully meets the standard, and there is no crack at the vertical plane of the flange transition, which meets the requirements for sample delivery.

Fig. 7 Lower die of preformed

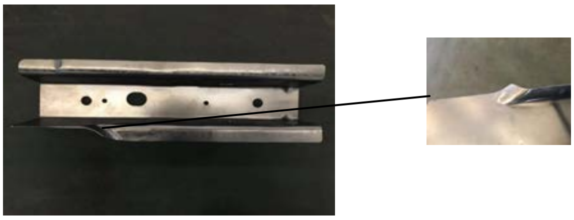

Fig8. Finished product chart

6. Conclusion

(1) Aiming at the problem of stamping and cracking of the rear longitudinally extending beam, it is proposed to further increase the preforming process, slow down the slope, make the material “climb” easier, enhance the material's fluidity, and reduce the risk of cracking on the product surface.

(2) Using the maximum thinning rate of forming and the maximum rebound amount after trimming as the objective function, take the five factors of product surface bending angle, punching speed, blank holder force, concave and convex die clearance, and friction coefficient as independent variables. The orthogonal test obtained the optimization results of each combination of process parameters, and then the gray correlation analysis was run to calculate the gray correlation coefficients and correlation degrees of the results of each group of test process parameters on the two goals of maximum thinning rate and maximum rebound. Through

ISSN 2616-7433 Vol. 2, Issue 8: 17-22, DOI: 10.25236/FSST.2020.020804

comparison, the optimal combination of process parameters is finally obtained: the product surface bending angle is 60 °, the concave-convex die clearance is 0.2mm, the friction coefficient is 0.15, the blank holding force is 800KN, and the punching speed is 2000 (mm / s).

(3) The simulation results show that the maximum thinning rate of the product is 12.5%. The actual trial production, the quality of the parts is qualified, and the stamping is good. The results show that the combination of gray correlation and orthogonal test can effectively improve the quality of the product, thereby reducing the test cycle, saving costs and improving production efficiency.

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