Stamping Analysis of an Automobile Support Plate
Based on DYNAFORM

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Abstract. Automobile covers and its support parts are important components of the automobile frame, and the support plate affect the automobile life and its safety. Crack and wrinkle are two key factors affecting the forming of automobile support plate. In this paper, the upper support plate of the automobile front bumper beam was taken as the object to study, and the DYNAFORM software was used to simulate and analyze its stamping process and do orthogonal tests. In orthogonal test, the wrinkling and maximum thinning rate were selected as the evaluating index, and then the two weighted mean values were calculated, and the minimum value was selected as the optimal combination of the gap between punch and die (0.62mm), friction coefficient(0.125), stamping speed (4000mm/s). And the DYNAFORM run showed that high stamping quality was achieved with the optimization parameters.

Introduction

With the development of social economy, the automobile become indispensable for people. As a large scale of industrial product, the automobile body is mainly made by stamping or sheeting. Automobile panels are required with some characteristics such as complex shape, large size, thin thickness and high surface quality. The stamping of automobile panel is based on the large deformation of metal, which has the characteristics of nonlinear mechanics of geometry, physics and boundary friction. Automobile body dies, especially cover dies, are important parts in the course of body dies development[1]. In the stamping of the traditional production process, both the designing and manufacturing of cover dies would go through repeated trying and debugging including process parameters and stamping process planning. And this is a process called trial and error which results in a large number of consumption of manpower, materials, financial costs, resources, and it causes high production cost and long cycle. Most surfaces of the automobile cover parts are composed of complex curved surfaces, which have the characteristics of large size and asymmetric shape, and the thickness of such part is relative small. The deformation state of different part of the blank is very complex in forming process, and the deformations include drawing, flanging, bulging, bending and other deformation with very uneven of stress distribution.

In stamping process, because the geometry of automobile is complex with many complex surfaces, some defects such as cracking, wrinkling and springback etc. could be caused or even lead covers to batches rejected. Therefore, in the forming process and die designing, special attention should be paid to the deformation uniformity of each rejoin of the part. these attentions include that 1) ensuring the maximum deformation of severe deformation zone does not exceed the material's allowable plastic range, 2) ensuring the material being un-cracked, 3) ensuring a small amount of material deformation area has no elastic distortion with sufficient rigidity after forming and 4) ensuring to prevent the springback, wrinkling and surface damage occurring in the process. With the popularization and development of computer technology, the processing and manufacturing of automobile stamping parts have ushered in a new revolution[2-3]. In the early stages of product development, CAE is used to simulate the stamping process, predict rupturing, wrinkling and springback defects in parts, optimize the forming process parameters. This is an indispensable step in
the development process, and many programs of numerical simulation of stamping and many enterprise standards have been developed, and their application is becoming more and more mature and credible [4, 5]. Mohamed [6] analyzed the effect of different distance of drawbead on the forming quality, and optimized their data, and obtained their satisfactory experimental results. In our studying case here, a upper support plate of car front bumper beam is analyzed based on DYNAFORM to prevent cracking, wrinkling and other defects, and an optimal solution based on orthogonal test is obtained.

Analysis of Technological Process of the Support Plate

Process and Material Selection

To ensure the automobile body having good performance in support and anti-impact conditions, front of the automobile anti-collision beam should have considerable assembly precision, surface roughness and rigidity. Therefore, the support plate must meet size precision and high forming quality requirements. In this paper, we use UG NX10.0 to establish the three-dimensional model of the upper support plate of the front bumper of the automobile, the 3D model is shown in Figure 1. The total length of the part is 698mm, the width is 78mm. The two ends of the supporting plate are opening, unclosed, and bilateral symmetrically; the part has large depth, which leads to large drawing depth. According to the characteristics of 3D model of the part and its forming features, we adopt some steps as follows. first, material cut, then stretching, then side flanging with shaping, finally side punching and trimming. For the front bumper of the automobile, the material of the upper support plate is DC04 deep drawing plate with 0.6mm thickness. Yield strength of the DC04 deep drawing plate is 130-210MPa, tensile strength is 270MPa, elongation is not less than 34%. Using DC04 deep drawing sheet as automobile cover material, although the vehicle has reached the goal of losing weight, increased the difficulty of forming process to a certain extent. It is prone to crack and springback according to the structure complexity of the three-dimensional model of the support plate, and this bring difficulties to the actual production. Therefore, this article will use the DYNAFORM software focusing on simulating the uneven material flowing after stamping process of the upper plate of the automobile front bumper beam.

Stamping Direction Determination

Whether the forming condition is good or not is related to the reasonable direction of stamping in determining the stamping direction. In stamping direction determination, the ultimate deformation of the largest material's deformation zone should not exceed the material deformation degree to avoid material cracking, and the minimum material deformation region should have no elastic distortion to avoid springback, wrinkling and other defects. After considering the factors such as the closing angle of mold, the stamping environment, the stamping process parameters and so on, it is determined that the stamping direction of the upper support plate is shown in figure 1.

Addendum and Blank Determination

The forming quality of automobile cover is related to the reasonable design of the addendum and blank. Addendum and binder surface being designed to be modified easily can improve the design
efficiency of parts. In order to make the parts forming with good quality, technological supplement is needed, material flow is adjusted to the final part. That is say, internal hole of parts should be filled. At the same time, binder surface should be constructed between the outer addendum surface and the tectonic transition surface. This ensures the forming movement not occurring in its final forming process. Considering the symmetry, the addendum and blank are determined shown in Figure 2.

**The Upper Support Plate Simulation and Analysis**

First of all, the UG NX10.0 3D model is output to .IGS format, then input .IGS format to DYNAFORM software. The addendum surface and part layer in binder surface are added to the die part layer in a concave die with part layer binder, then mesh. Check the boundary of the grid to determine whether there exists gaps. If there is any gap, then repairs should be carried out. Here, there is no gap.

Figure 2. Addendum and blank are determined (A-binder; B- Addendum; C-product ).

Then the tools (punch and die) are derived and meshed, and the DYNAFORM finite element model is constructed shown in figure 3. Input the blank contour line, definite the blank thickness 0.6mm, select DC04 (T37) as materials, Selecting 4 points for unit 16 as its formula, defining friction coefficient 0.125, setting the gap between punch and die 0.6mm, stamping speed 5000mm/s, then submitting to the solver to calculate for post processing, the image of forming limit diagram and thickness calculation results are shown in Figure 4. In the ETA/Post post processing forming limit diagram, the red zone represents easy to be cracked, the purple zone and the pink to be wrinkled. It is shown that, some places in binder region and middle region of the flange are easy to be wrinkled, but these does not affect forming quality of flange area caused by wrinkling, they would be cut off later. There is a large number of cracks in the edge and fillet region, which is to be avoided in the production process. This paper considering punch and die clearance, the blank holder force and friction coefficient to solve the problem of drawing wrinkling and cracking. In this paper, in order to gain a better forming quality, the orthogonal test method is carried out, and the problem of large area cracking of the fillet zone is solved, and the parameters of the upper support plate of the front bumper beam is optimized.

Figure 3. DYNAFORM model of concave die and punch.

**Orthogonal Test Designing**

The friction coefficient, forming speed and die clearance obviously are factors influence on the drawing process, and they are not mono factor, they are interactive. In the process of forming, lacking or improper lubrication, the friction would be very large, cracking would be caused in parts stamping; and the same effect does the greater speed. If the gap between punch and die is too small, cracking would be induced in some region of parts. Therefore, in order to analyze the reasonable combination
of the three factors, evaluate their influence on the forming of stamping drawing, an optimal solution would be carried out.

In order to find the optimal solution, we introduce the orthogonal test. The orthogonal test is a design method of multi factors and multi levels, which is based on the orthogonality of the selected representative points to test, these representative points have a homogeneous dispersion regularity.

The experimental results show the maximum thinning rate and the wrinkling rate among the different combination of parameters. The smaller the value of the maximum thinning rate and wrinkling rate, the better the forming quality of the parts.

Figure 4. Forming limit diagram (FLD) and thickness cloud diagram of the upper support plate.

In the post-processing of DYNAFORM, unit with minimum thickness of the minimum thickness is found, and then thinning rate is calculated. Setting the initial blank thickness is $t_0$, the minimum thickness of plate when drawing forming is completed $t$, the biggest thinning rate of the part $f$ is defined as follow:

$$f = \frac{t_0 - t}{t} \times 100\%$$ (1)

In DYNAFORM post-processing in the forming limit diagram (FLD), the total unit number before the running of solver is $s_0$, the number after the completed of drawing of wrinkled units is $s$, the wrinkling rate of part $p$ is defined as follow:

$$p = \frac{s}{s_0} \times 100\%$$ (2)

Finally, using the weighted score $Q$ of the maximum thinning rate and the wrinkling rate, set $W_1$ as the weight coefficient of the maximum thinning rate, $W_2$ is the weight coefficient of the wrinkling rate, and $W_1 + W_2 = 1$, then the comprehensive weighted score $Q$ is defined as follow:

$$Q = W_1 f + W_2 p$$ (3)

Accordingly, the smaller the value of the comprehensive score $Q$, the better the forming quality. However, in practical applications, the value of the weighting factor should be determined according to the different degrees of fracture, wrinkling and deformation. According to the forming characteristics of the upper support plate of the front anti-collision beam of the automobile, the weighted coefficient combination we established is shown in Table 1.
According to the analysis above, a three factors and two levels orthogonal test table is developed, and the result of orthogonal experiment analysis with small value is the set of result we chose. The reasons why large area cracking in parts were caused like in figure 6 are in many aspects. According to the three factors involved in the design of the orthogonal experiment, 0.125 and 0.120 friction coefficient, 4000mm/s and 5000mm/s stamping speed are determined. And the total clearance between punch and die is less than expected 1.1 times of the thickness, is between 0.6mm-0.66mm, so 0.62mm and 0.61mm of the gap are determined. Factors level table is shown in table 2.

Table 1. Weighted coefficient distribution table.

| Weight combination | W₁ | W₂ |
|--------------------|----|----|
| Q₁                 | 0.6| 0.4|
| Q₂                 | 0.7| 0.3|
| Q₃                 | 0.8| 0.2|

Table 2. Orthogonal experiment table.

| Level | Factors | Experimental result |
|-------|---------|---------------------|
|       | A (mm)  | B (mm/s) | C                     | Maximum thinning rate(%) | Wrinkling rate(%) |
| 1     | 0.61    | 0.125    | 5000                 | 26.705                 | 16.862           |
| 2     | 0.62    | 0.120    | 4000                 | 26.628                 | 16.942           |
| 3     | 0.61    | 0.120    | 5000                 | 26.382                 | 17.046           |
| 4     | 0.62    | 0.125    | 4000                 | 27.031                 | 14.233           |

Table 3. Evaluation index of weighting coefficient.

| Q₁ | Q₂ | Q₃ |
|----|----|----|
| 22.753 | 23.752 | 24.736 |
| 22.754 | 23.722 | 24.691 |
| 22.648 | 23.581 | 24.515 |
| 21.912 | 23.192 | 24.471 |

Test Result Analysis

The test results in terms of the provisions of the comprehensive evaluation criteria are shown in Table 3, and for the corresponding weight combination Q₁, the fourth group experimental data of 3 kinds of comprehensive weight is the smallest, and it is inferred that this is the optimal combination of parameters. The optimal solution with the level of each factor of the support plate of automotive front bumper beam then is input and analyzed in DYNAFORM, and the cloud forming limit diagram and the corresponding thickness are obtained. They are shown in Figure 5. Comparing the post-processing graphical shown in Figure 4, it is shown that the cracking zone reduce largely, and it lies only in the addendum in Figure 5, and this region will be removed later. It also shows that the maximum thinning rate decreased from 86.733% to 27.031%, shows a significant improvement.

Conclusions

1) Numerical simulation of DYNAFORM drawing process on the upper part of the support plate of automotive anti-collision beam is carried out, and the results shows that the maximum thinning rate with maximum wrinkling could be weighted as comprehensive evaluation index to construct an optimal model, and an optimization process parameters could be gained. In this case, the best forming quality could be obtained with the fourth sets of experimental data. They are the punch and die clearance 0.62mm, the friction coefficient 0.125, stamping speed 4000mm/s. Running with these parameters, the maximum thinning rate is 27.031%, the wrinkling rate is 14.233%. the simulation and the orthogonal experiment could control effectively and reduce the cracking and wrinkling, improve the stamping quality.
2) In the case here, the plate size is too big, and a large number of wrinkling are caused, anyway, the results is not beyond the scope of permission. Aiming at the problem that it is not sufficient to be drawn in the middle of the part, next step such as changing the resistance of materials flowing and drawbead layout would be adopted, and the stamping quality could be improved in these regions.

3) When the simulation is carried out by the comprehensive weighted grading criterion, the simulation results to the fracture or wrinkling is different because of the parameters’ different weight coefficients. However, in practical applications, the value of the weighting factor should be determined according to the different degrees of fracture, wrinkling and deformation. In the case of support plate of front bumper beam here, the weight combination for maximum thinning rate and wrinkling rate is $W_1=0.6$ and $W_2=0.4$ respectively.

![Figure 5. The FLD scheme and the thickness map of the optimal scheme under the combination of Q1 weights.](image)

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