Simulation Study on Hot Stamping Forming of the Drive Axle Housing of Heavy Truck

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Abstract. Aiming at the national energy-saving and emission reduction requirements, lightweight of the heavy truck is imminent. Several parameters related to hot stamping forming process of heavy truck drive axle housing are studied in this paper. The results show that the existing two-step stamping with air cooling molding process, can be improved into one-step hot stamping process. The initial temperature of the blank, stamping speed and other parameters related to the forming process were optimized. The results provides useful reference for improving the existing forming process of the drive axle housing, and it is also helpful for realizing the lightweight design of drive axle housing.

1. Introduction

As the energy crisis is getting worse and worse, and the air pollution control requirements are getting higher and higher, lightweight design of vehicles and lightweight technology development have been paid more and more attention. At present, the lightweight work of passenger car has achieved remarkable results. However, lightweight work in the commercial vehicles field is not perfect.

The application of high-strength steel has obviously enhanced the performance of vehicles and its parts [1, 2]. The drive axle housing is an important part of the heavy truck drive axle, which supports and protects the main reducer, differential and so on, it also fixed drive wheel relative position, and support the frame and the total mass above it together with the front axle. However, when manufacturing the axle housing using high-strength steel plate, there are many problems such as cracking and rebound if the traditional forming process is used [3]. This is because high-strength steel has larger deformation resistance at room temperature, and it is difficult to shape, and the mold will also cause great wear, which will lead to significant reduction of the life of the mold [4].

The biggest characteristic of hot stamping is that the part is formed at high temperature. For the heavy truck drive axle housing, one aspect is that it is thicker than normal thin wall parts, the other aspect is that the axe housing with zero draft angle, one-step forming is easy to cause demoulding difficulties, so, although the current drive axle housing is stamped at high temperature, but most of them using two-step stamping technology with air-cooling process. The drawback of this technique is the uncontrollable cooling rate, which leads to uncontrollable metal phase transformation during the cooling process. Thus, the enhancement of the performance of high strength steel sheet is limited. While the one-step forming technology can control the cooling rate by inside-die cooling technology [5, 6], so it can control the metal phase change during the cooling process, and can obtain ultra-high strength parts.
For the drive axle housing, the mold has a relatively larger stroke in stamping process, so the parameters such as appropriate stamping speed and initial blank temperature are the key factors of the hot stamping technology, which can avoid wrinkling, cracking and even tear in the stamping process. In this paper, the shell element is used to conduct a thermoforming analysis of the drive axle housing to determine the optimal values of the two parameters mentioned above. The inside-die cooling technique can significantly improve the strength and rigidity of the axle housing, so it provide space for the steel plate thinning. Which can reduce the weight of the axle housing, and achieve the purpose of energy saving.

2. Hot Stamping Model of Drive Axle Housing
The drive axle housing is formed on the basis of semi-housing by butt welding, the solid model of semi-housing is shown in Figure 1.

According to this semi-housing model, using the mid-plane extraction function and the blank development function of the software to generate the blank model, and then generate the punch and the die on the basis of the semi-housing. The complete semi-housing hot stamping model is shown in Figure 2.

![Figure 1. Semi-model of drive axle housing](image1)

![Figure 2. Hot stamping forming model of drive axle housing](image2)

3. Stamping Forming and Analysis of Drive Axle Housing
After setting up the material constitutive model, the process parameters and so on [7, 8] for the thermoforming model, the simulation work of the forming process of the drive axle housing is carried out using shell element. In this paper, the effects of mesh size, stamping speed and initial blank temperature on forming quality were studied.

3.1. Effect of Mesh Size on Forming Quality
In the finite element simulation, the mesh size has obvious influence on the calculation results. In general, the smaller mesh size will bring large-scale calculation and accurate results; and bigger mesh size will lead to faster calculation speed, but may has lower accuracy. In this paper, the calculation of the drive axle housing models was firstly carried out using different mesh sizes with the same
stamping speed (650mm / s) and the same initial blank temperature (850 °C) [9]. The forming quality is summarized in Table 1.

It can be seen from table 1 that using shell element to simulate the forming process of the blank with a thickness of 14mm, the forming quality is unqualified when the mesh size is 28mm, 42mm, 84mm, 98mm respectively. In general, it is believed that if any region of the part has a thickness increment more than 2%, or has a thinning rate more than 20% during the stamping process, it is unqualified [10,11]. The smaller the thinning rate is, the better the forming quality is, so the best mesh size is 63 mm.

Table 1. Forming quality of drive axel housing with different mesh sizes

| Mesh size(mm) | Forming limit    | Min. thickness(mm) | Max. thinning rate | Max. end temperature(°C) |
|---------------|------------------|--------------------|--------------------|--------------------------|
| 28            | Crack occur      | 9.78               | 35.9%              | 789.948                  |
| 42            | Risk of crack    | 11.145             | 22.8%              | 789.852                  |
| 56            | Qualified        | 11.631             | 18.5%              | 790.094                  |
| 63            | Qualified        | 11.789             | 17.2%              | 789.694                  |
| 70            | Qualified        | 11.741             | 17.6%              | 790.090                  |
| 84            | Risk of crack    | 11.364             | 21.8%              | 790.675                  |
| 98            | Crack occur      | 10.785             | 27.6%              | 791.373                  |

Figure 3 shows the forming limit distribution with different mesh sizes.

![Figure 3](image_url)

Figure 3. Forming limit diagrams of models with different mesh sizes

It can be seen from Figure 3 that either too small or too large mesh size will result in varying degrees of cracks areas, risk of crack areas or areas with wrinkling trends at the end of stamping.

Figure 4 shows the thinning rate distribution with different mesh sizes.
Figure 4. Thinning rate distribution of models with different mesh size

It can be seen from Figure 4 that either too large or too small mesh size is will lead to excessive maximum thinning rate of the drive axle housing at the end of stamping. And the local thickening rate will also exceeds the standard with too large mesh size.

For those three mesh size as 56mm, 63mm and 70mm that meet the forming quality requirements, because 56mm and 70mm are at the boundary between qualification and disqualification, in order to avoid unqualified forming quality because the change of the stamping speed and the initial blank temperature, the middle size of 63mm was adopted as the optimized size to perform the optimal calculation for stamping speed and initial temperature.

3.2. Determination of the Optimal Stamping Speed

After the optimal mesh size was determined, the effect of stamping speed on the forming quality was investigated. Since the stamping speed will affect the forming quality, and it also influence the production beats and other factors as the selection of press machine model. The stamping speed is selected in the range of 400-800mm/s. The forming quality of different stamping speed is summarized in Table 2.

Table 2. Forming quality of drive axle housing under different stamping speeds

| Stamping speed (mm/s) | Forming limit  | Minimum thickness (mm) | Maximum thinning rate | End temperature (°C) |
|-----------------------|----------------|------------------------|-----------------------|----------------------|
| 400                   | Crack occur    | 9.313                  | 40.9%                 | 755.867              |
| 500                   | Risk of crack  | 10.908                 | 25.0%                 | 772.930              |
| 550                   | Qualified      | 11.302                 | 21.4%                 | 779.542              |
| 600                   | Qualified      | 11.589                 | 18.9%                 | 784.800              |
| 650                   | Qualified      | 11.789                 | 17.2%                 | 789.694              |
| 700                   | Qualified      | 11.872                 | 16.5%                 | 793.803              |
| 750                   | Wrinkle tendency | 11.959             | 15.8%                 | 797.357              |
| 800                   | Wrinkle tendency | 11.999             | 15.4%                 | 800.553              |

It can be seen from Table 2 that the stamping speed has a great impact on the forming limit. A small stamping speed will result in cracked surface of the drive axle housing, and wrinkled surface will occur on the drive axle housing when the stamping speed is too large. The maximum thinning rate decreases monotonically with the increase of stamping speed, but the temperature at the end of stamping increases monotonically. The reason is that the blank strength is low under high temperature, the wrinkle area will occur as the blank is driven by the large inertia of the punch before the mold
closed completely if the stamping speed is too large. On the other hand, if the stamping speed is too small, there will be a relatively long time and uneven heat exchange between the drive axle housing and the mold, which lead to local low surface temperature on the drive axle housing surface, so obvious thinning or even crack will occur.

Figure 5 is the temperature distribution at the final moment of stamping with optimal mesh size and different stamping speeds. It can be seen from Figure 5 that even the minimum stamping speed of 400mm/s is selected; the minimum temperature of the drive axle housing is still up to 423.869 °C, which is larger than the martensitic transformation temperature [12]. In other words, during the stamping process, the toughness will not decrease due to temperature changes. So it is qualified to select the blank initial temperature as 850 °C.

Figure 6 is the forming limit diagram at the end of stamp forming for different stamping speed with the optimal mesh size. It can be seen from Figure 6 that there will be crack area and wrinkling area if the stamping speed is too low or too high. In the qualified speed zone, the potential crack area or wrinkling area is located at the edge of the semi-housing, which can be solved by trimming before the butt welding.

![Temperature distribution at the end of stamp under different stamping speeds](image1)

**Figure 5.** Temperature distribution at the end of stamp under different stamping speeds

![Forming limit diagram of drive axle housing under different stamping speeds](image2)

**Figure 6.** Forming limit diagram of drive axle housing under different stamping speeds
Comprehensively considering this problem, the best stamping speed can be determined as 650mm/s, under the premise that the mesh has optimal size. At this speed, there is no crack or wrinkle at the end of stamping, and the maximum thinning rate meets the requirement.

3.3. Determination of the Blank Initial Temperature
After determined the optimal mesh size of the shell element and the optimum stamping speed, the optimum blank initial temperature was investigated. Since the initial blank temperature is related to the temperature in the furnace, and then to the heating time and production capacity. Taking reference to the maximum temperature of 850 °C in paper [9], this paper calculates at 825-925 °C and 25 °C intervals. The quality of the drive axle housing is summarized in Table 3 below.

It also can be obtained from Table 3 that the initial temperature of the blank has a great impact on the forming quality of the drive axle housing. Due to factors such as material properties, temperature in the furnace, heat transfer between surrounding environment and blank as the blank is transferred from the furnace to the mold, the actual initial temperature of the blank at the start of stamping is difficult to exceed 900 °C. Therefore, the simulation result at a temperature more than 900 °C does not have much guiding significance for actual production.

When the temperature is low, the blank will rupture. And when the temperature is too high, wrinkling may occur. The reason is that at low temperature, the axle housing may not be fully austenitized, so part of the axle housing surface cracked. And if the temperature is too high, the strength of the axle housing significantly decreased, and the ability to resist deformation is low, so it is easy to wrinkle. Comprehensively considering the thinning rate, the temperature at the end of stamping and other factors, 875 °C is considered as the most reasonable initial blanking stamping temperature.

Table 3. Forming quality of drive axle housing with different initial temperature

| Initial temperature(°C) | Forming limit | Minimum thickness(mm) | Maximum thinning rate | End temperature(°C) |
|--------------------------|---------------|-----------------------|-----------------------|---------------------|
| 825                      | Risk of crack | 11.581                | 19%                   | 774.072             |
| 850                      | Qualified     | 11.631                | 18.5%                 | 790.094             |
| 875                      | Qualified     | 11.847                | 16.7%                 | 810.148             |
| 900                      | Qualified     | 11.606                | 18.8%                 | 830.497             |
| 925                      | Wrinkle tendency | 11.768                | 17.4%                 | 850.404             |

Figure 7 shows the forming limits for the model with the best parameters. It can be seen that the semi-housing of the drive axle has a very good molding effect, no cracks or wrinkles, wrinkled edge can be solved by trimming process.
4. Conclusion
The thermoforming process of the drive axle housing is worth promoting. The forming quality is closely related to stamping speed and the blank initial temperature.

The heavy truck drive axle housing has a larger thickness, this study shows that one-step stamping forming technology is feasible. The existing two-step stamping forming with air cooling process can be improved. The research results of this paper can provide useful references for process improvement and selection of new process parameters.

However, due to the thickness of the heavy truck drive axle housing is much larger than the thickness of common hot stamping parts, the simulation accuracy of such components using shell element will be affected in some extent. Performing thermoforming simulation of the heavy truck drive axle housing based on solid element will provide more reasonable and reliable, more accurate reference for the improvement of the process, which is the future direction of such research work.

5. References
[1] Wang Z T, Zhang S H, Xu Y C, etc. Study on the Technology and Limit Drawing Ratio of Magnesium Sheet Stamping [J]. Journal of Shenyang Institute of Technology. Shenyang. 2004, Vol.23, No.4: p 1-3.
[2] Fan J F, Feng Q, Ling T J, etc. Automobile Lightweight and Manufacture Technology [J]. Machinery Design & Manufacture. Shenyang. 2009(7): p 141-143.
[3] Hoffmann H, So H, Steinbeiss H. Design of Hot Stamping Tools with Cooling System. CIRP Ann Manuf. Technol., 2007(56): p 269–272.
[4] Wang H J, Fan H Y. The Hot Forming Technique in the Car body Manufacture [J]. China Mould, Beijing. 2005(4): p 32-34.
[5] Ma N, Shen G Z, Zhang Z H, etc. Material Performance of Hot-forming High Strength Steel and Its Application in Vehicle Body [J], Journal of Mechanical Engineering. Beijing. 2011, 47(8): p 60-65
[6] Ying L, Jia Z Y, Hu P, etc. Improvement of Hot Stamping Process for High Strength Steel [J]. China Metal forming Equipment & Manufacturing Technology. Jinan. 2013(1): p 75-78.
[7] Tobias O. An LS-DYNA Material Model for Simulation of Hot Stamping Processes of Ultra-high Strength Steels [A]. 7th European LS-DYNA Conference [C]. 2009, Salzburg (Austria) and Bad Reichenhall (Germany).
[8] Paul A. Modelling and Simulation of Hot Stamping [D]. Lulea: Lulea University of Technology, 2006.
[9] Bi W Q, Wang C Z, Chen G. Numerical Simulation on the Hot Press Forming Process of Axel Housing [J]. Materials Science & Technology. Harbin. 2008, Vol16 (4): p 488-490.
[10] Han Y Q, Li F Z. Research of Stamping Form Simulation for Hood Outer Panel Based on Dynaform [J]. Hot Working Technology. Beijing. 2010, 39(15): p 96-98.
[11] Shan Yun. The Optimization Design of Hot Stamping Process Parameters Based on the Numerical Simulation [J]. Machinery Design & Manufacture. Shenyang. 2014(12): p 173-175
[12] Yang X C. Research on Cooling System of Hot Forming Tools [D]. Jilin: Jilin University. 2015