Research on hot stamping process of tailor-welded blanks integrated door ring

Nixia Sun†, Bei Xu, Jun Ma, Hongjun Qiao, Shidong Yin, Jun Deng and Weiwei Cheng

Dongfeng Mold Stamping Technology Co., Ltd., Wuhan 430070, China

**E-mail: sunnixia2006@163.com*

This article studies the overall hot stamping forming process and quality improvement of passenger car door rings. As a key component of vehicle, the stability of the door ring's quality and dimensional accuracy is crucial to the overall quality of the vehicle. However, in the large-scale production process, problems such as missing edges, cracking of parts, cracking of welds, deformation rebound of parts, deformation of parts, indentation of parts, and unstable hole positions have emerged, seriously affecting the stability of product quality. To address these challenges, this article proposes a series of improvement measures, including optimizing process parameters, adjusting mold structures, and strengthening quality control protocols. These measures effectively address the aforementioned quality issues, thereby enhancing the stability of product quality and dimensional accuracy. This study not only provides technical support for the production of door rings for vehicles, but also provides solutions to improve the competitiveness of the products.

Keywords: Off-road vehicle door ring; Tailor welded blanks; Hot stamping; Process and mold; Quality stability.

1. Introduction

The significance of high-performance metal sheet hot stamping forming technology in automotive lightweighting cannot be overstated and has seen extensive use. With the continual advancement of ultra-high-strength steel hot stamping forming technology, it has progressed from simple part forming to intricate structural shaping [1]. By considering the distribution of collision energy and load paths in lightweight body structural components, laser welding is employed to join sheet metals of varying thicknesses and strength levels. Subsequently, integrated hot stamping forming is utilized to produce lightweight body components with a strategically balanced distribution of high-strength plasticity areas [2]. Laser welding is the optimal joining process for high-strength steel, which involves welding different materials, thicknesses, and shapes of plates into a single blank, followed by hot stamping forming. ArcelorMittal and Honda collaborated in 2014 to develop the world's first hot stamping door ring made from ultra-high-strength welded plates [3]. In 2018, they introduced the world's first ultra-high-strength inner-outer door ring based on the Acura RDX platform. In 2021, ArcelorMittal proposed the MPI concept based on years of technological development [4]. MPI technology combines the advantages of ultra-high-strength steel laser welding and hot stamping technology, and it has been widely applied in lightweight body structures [5].

Y. Zhang and M. Ma (eds.), *Proceedings of the 7th International Conference on Advanced High Strength Steel and Press Hardening (ICHSU 2024)*, Atlantis Highlights in Materials Science and Technology 3,
https://doi.org/10.2991/978-94-6463-581-2_5

2. Material and Welding Design of the Integrated Vehicle Door Ring

The main process characteristics of body-integrated door rings are: high-strength steel material, stitching and welding process, and integrated hot stamping. The raw material is usually high-strength steel, using its high yield and tensile strength, better hot stamping performance, in order to provide sufficient strength and stiffness, and at the same time to achieve the lightweight of the body. The body unibody door ring usually consists of multiple components, of which the splicing welding process is a key part of realizing the integration of multiple components, through which multiple components are connected together to form an overall spliced sheet. The design of the welding process needs to take into account where and how the components are connected, as well as the strength and stiffness requirements of the welded joints. Laser welding is a high energy density welding method for joining high-strength steel materials. During laser stitch welding, a laser beam is focused on the welded joint, generating high temperatures and high energy densities that instantly melt and join the material. Laser welding has the advantages of small heat-affected zone, fast welding speed and high quality of weld seam. Multi-component integrated hot stamping is a process whereby a number of spliced plates of material pieces of different material strength classes and plate thicknesses are formed in a single pass in a hot stamping and forming process by controlled heating and cooling to achieve a product of the desired shape, size and strong plasticity.

In summary, the integrated vehicle door ring typically uses high-strength steel material and realizes component integration through laser welding technology. Laser welding has the advantages of high efficiency and high quality, which can meet the manufacturing requirements of the integrated vehicle door ring [6]. Meanwhile, integrated hot stamping technology enables one-step forming of components, improving production efficiency and stability of product quality.

The material grade of the hot stamping high-strength steel used for the integrated door ring of this car is 1300 to 15000MPa, with thicknesses of VP1/T=1.4mm, VP2/T=1.5mm, VP3/T=1.2mm, and VP4/T=1.2mm. The new generation wire filling welding process is used for welding, and the maximum size of the blank is 1591X1651mm, as shown in Figure 1. Through hot stamping forming simulation, the thinning status of the formed part is obtained, as shown in Figure 2. The maximum thinning amount is -0.135, which is still within the safe thinning range.

3. Defects in Hot Stamping Products and Solutions

3.1. *Influence of Blank Deviation on Forming*

Hot stamping is a process that uses hot plates in a mold to create complex shaped parts. In the hot stamping and forming process, the dimensional accuracy of the blank has an important effect on the forming performance. Errors in the blank will directly affect the formability, surface quality and dimensional accuracy of the part. Shape errors in the blank also have an impact on forming performance: if the blank is not shaped accurately before forming, for example, if there are problems with twisting, skewing, or bulging, uneven stresses are applied to the mold during the forming process, resulting in a molded part that is limited in shape complexity, and may not fully conform to the intricate curves or details required by the design. Dimensional errors in the blank can also have an impact on the surface quality of the formed part: if the blank has large dimensional errors, the material may overstretch or underfill during forming, resulting in wrinkles, imperfections, or uneven stretching on the surface of the part. This can degrade the surface quality of the part and may even affect the life and function of the part. Dimensional errors in the blank can also lead to inaccuracies in the dimensions of the formed part: if the blank is oversized or undersized, the dimensions of the formed part will deviate accordingly. This can result in parts that do not meet the dimensional accuracy required by the design, which can cause problems for parts that require a precise fit or for demanding assembly processes.

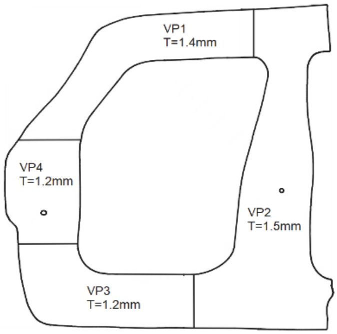

Figure 1 Design of LWB for door rings

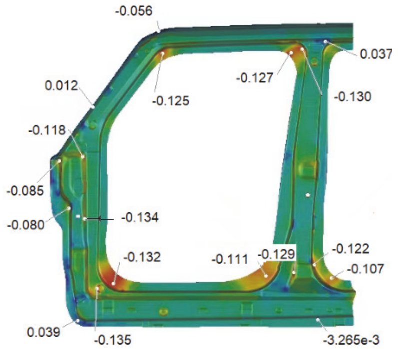

Figure 2 Forming Simulation - Thinning Analysis

Therefore, in the hot stamping forming process, in order to ensure the quality of the formed parts, it is necessary to control and reduce the dimensional and shape errors of the blank. This can be achieved through the scientific use of blank unfolding software, optimizing blank processing techniques, and strictly controlling the dimensional and shape processing accuracy of the blank. Suitable temperature, pressure, and time parameters should be applied during the forming process. Additionally, evaluation of the influence of blank errors on forming performance through simulation analysis and experimental verification can help formulate compensation measures and optimization strategies to improve the quality and consistency of the formed parts. Due to errors in the projection direction, there is a significant deviation in the size of the blank line, resulting in missing edges in the formed parts. This problem can be solved by correcting the projection surface and improving the accuracy of the blank processing. In addition, the excessive height of the weld seam in the raw material requires optimizing the cutting process and mold structure of the welded panel, as shown in Figure 3. For $t2 \leq 1$mm, the requirement is that the weld seam excess height $h \leq 0.1$mm; for $t2 > 1$mm, the requirement is that the weld seam excess height $h \leq 0.1 x t2$. For wire filling welding, the requirement is that the weld seam excess height $h \leq 0.15 x t2$. Weld seam undercutting, as shown in Figure 4, can also affect the dimensional stability of the product.

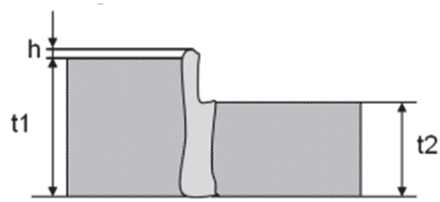

Figure 3 Excessive Height of Weld Seam Affects Die Closure and Formability

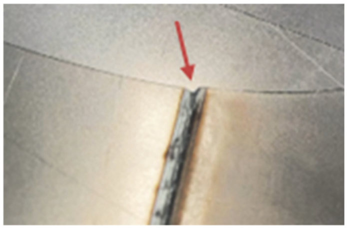

Figure 4 Weld Seam Undercutting Should Be Avoided

3.2. *Cracking of Hot Stamped Parts*

Cracking can occur in the hot-stamped parts during the forming process, as shown in Figure 5. Factors such as the gap between the press plate and the concave die due to the heating expansion of the sheet, the geometry of the blank material, the thickness distribution and the location of the holes can have an effect on the cracking. The size of the hot stamping pressure also has an important effect on the success of hot stamping and forming, and too much or too little pressure may lead to cracking of the material. In the trial mold of this study, through simulation analysis and experimental verification, it was found that the hot stamping cracking problem of the door ring was mainly caused by the heating and expansion of the material sheet, which resulted in the gap between the press plate and the concave mold being too small, the material flow rate being slow, and the material being excessively thinned. By adjusting the gap between the die platen and the concave die, the cracking defects of the door ring hot stamping parts can be eliminated, and the forming quality and consistency of the hot stamping parts can be improved. Secondly, the reasonable design of the shape of the blank material (spliced plate) is also a key process technology, avoiding overly complex geometries, minimizing the thickness difference, and reasonably laying out the holes to disperse the stress. Optimize the pressure parameters by design, determine the appropriate pressure range according to the nature and shape characteristics of the material, and avoid excessive or insufficient pressure application.

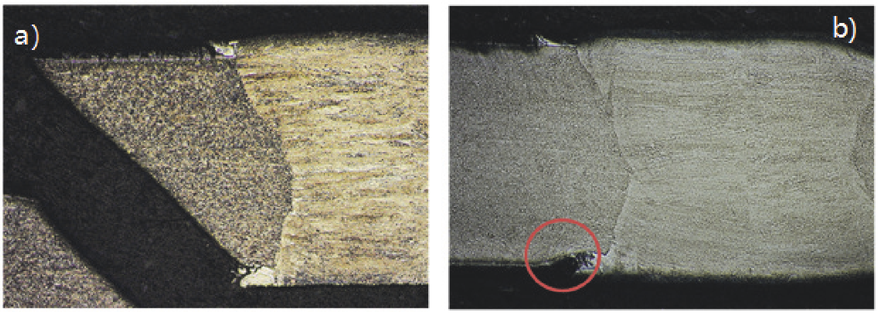

Figure 5 Microscopic Observation Photos of Weld Seam Cracking: a) Fracture surface, b) Crack surface

3.3. *Improvement of Weld Seam Cracking*

The main cause of weld seam cracking is the presence of concave areas in the base material and foreign material intrusion into the base material near the weld seam. Therefore, it is necessary to control the quality of the welded joint, improve the weld seam quality through optimizing the cutting process and mold structure.

The concave area of the base material is prone to stress concentration, which can lead to weld cracking. To avoid stress concentration caused by concave surfaces, the surface flatness and shape of the base material can be improved by optimizing the cutting process. For example, using more precise cutting equipment and cutting parameters to obtain a smoother surface of the base material. In addition, subsequent processing methods such as grinding or trimming can be used to repair and level the concave areas on the surface of the base material, reducing stress concentration.

In order to ensure cutting quality and reduce the impact of splashes on flat welds, an optimized cutting and material dropping route is adopted, as shown in Figure 6. Two splicing edges on the same blank must be cut synchronously. To ensure the quality and cleanliness of the welded edges, it is necessary to first cut the non-welded edges in the order of optimization (see the numbering in Figure 6, starting from numbers 1.2,…,4), and finally cut the welded edges. If a mold is used for material cutting, the designed weld edge precision cutting blade should have sufficient stiffness, the seams of the modules should avoid spliced overlap areas, and the stiffness requirements can also be met through supplementary structural design to achieve good cross-sectional quality and minimize burrs.

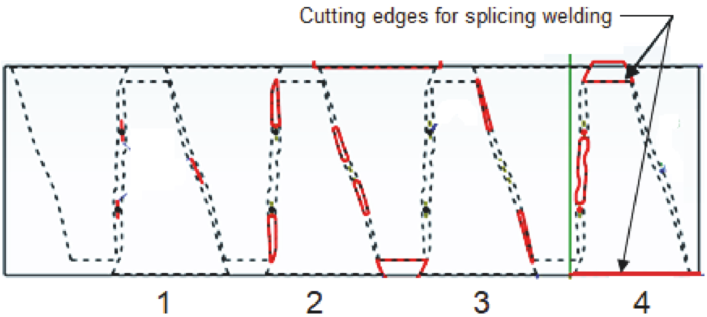

Figure 6 The order of material cutting for splicing welded plates

3.4. *Control of Part Distortion and Springback*

The issue of part distortion and springback in hot-stamped parts is usually related to mold fitting rate and process parameter selection. To control part distortion and springback, the following measures can be taken.

3.4.1. *Improve Mold Fitting Rate*

Mold fitting rate refers to the ratio of the contact area between the mold and the part to the contact area of the part. A higher mold fitting rate provides better cooling consistency, reducing thermal stress deformation and springback of the part due to different cooling temperatures during the cooling process. To improve the mold fitting rate, the stiffness of the load area of the mold can be increased, the geometric shape of the mold can be designed reasonably, and the surface processing accuracy of the mold can be improved, increasing the contact area between the mold and the part and providing better support and restriction.

3.4.2. *Optimize Hot Stamping Process Parameters*

Reasonable selection and adjustment of process parameters can reduce part distortion and springback.

In the mold trial, the optimal process parameters were determined through temperature analysis, and then a design of experiments (DOE) was conducted to confirm the process parameters. The experiment showed that after continuous stamping of the door ring mold for four times, the mold temperature reached a steady state, and the part ejection temperature ranged from 99 to 199°C.

In the process of experimental optimization, cooling simulation analysis was also used to evaluate and optimize the process parameters, achieving better control of water flow velocity, as shown in Figure 7. From the simulation results, the minimum flow velocity was 0.2m/Sec, and the maximum flow velocity reached 2.0m/Sec. The majority of the flow channels had flow velocities between 1.55-1.85m/Sec. By optimizing the cooling parameters, stable dimensional accuracy was achieved.

3.5. ***Laser Cutting Positioning Holes for Hot Stamped Parts***

In the post-processing of hot stamped parts, a three-dimensional laser cutting machine is commonly used for edge trimming. Laser cutting relies on the positioning holes pre-designed on the hot stamped parts for coordinate positioning of the cutting machine. The instability of hole positions in hot stamped parts is usually caused by changes in the sub-positioning hole locations due to material flow during the hot forming process. To improve the positioning stability of the parts, optimizing the shape and size of the positioning holes can be considered to enhance the fixing effect and reduce the influence of material flow. Here are some possible solutions.

3.5.1. *Control of Positioning Hole Size and Layout Optimization*

The size of the positioning holes is also crucial for positioning stability. Positioning holes that are too large or too small can both result in unstable hole positions. Therefore, careful control of the sizing of the positioning holes is needed to ensure proper matching with positioning pins or fixtures and achieve good positioning effectiveness.

Optimizing the layout of the positioning holes to provide better stability and support is important. Increasing the number of positioning holes or adjusting their positions appropriately to accommodate the shape and loading conditions of the parts can achieve more stable positioning effectiveness. By arranging the positioning holes in a reasonable manner, a more stable positioning effect can be achieved.

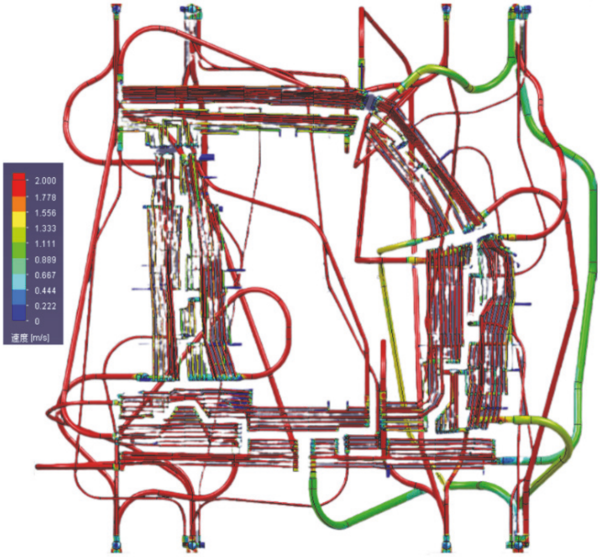

Figure 7 Simulation Results of Water Channels and Water Flow Velocity for the Door Ring Mold

3.5.2. *Optimization of Laser Cutting Positioning Hole Shape*

Changing the shape of the positioning holes can be attempted, such as using elliptical or irregular holes instead of traditional circular holes. These non-circular hole shapes can provide a larger contact area and normal support. Properly designing the shape of the positioning holes can increase the contact area with positioning pins or fixtures, thereby improving positioning stability. In this study, the long side of the sub-positioning hole was modified to a flanged hole, and the part was positioned on the laser cutting fixture using a combination of a circular flanged hole and a long elliptical flanged hole, as shown in Figure 8. Due to the stable hole diameter, the positioning stability during subsequent laser cutting was significantly improved.

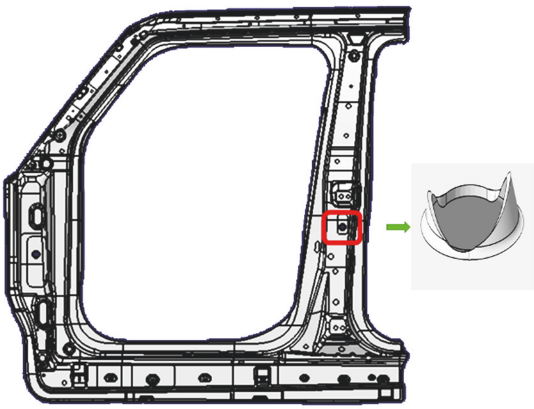

Figure 8 Achieving Accurate and Stable Laser Cutting Positioning through Optimization of Sub-Positioning Hole Form.

4. Conclusion and Future Outlook

By delving into the intricacies of the hot stamping forming process and quality control objectives pertaining to the integrated door ring, this paper presents a range of enhancement strategies. Through the optimization of process parameters, refinement of mold structures, and enhancements in quality control measures, a myriad of quality issues including missing edges, part cracking, weld seam cracking, part distortion and springback, part deformation, part indentation, and unstable hole positions have been effectively addressed. This has resulted in a notable improvement in the stability of product quality and dimensional accuracy.

However, certain issues still require further research and improvement, such as the challenge of high weld height and weld bottom cutting. Subsequent investigations can delve into these specific challenges with the aim of proposing more targeted and effective solutions. The research results of this article not only provide technical support for lightweight design of vehicle bodies, but also provide practical solutions for improving the competitiveness of passenger car door rings in large-scale production.

References

1. H. Karbasian, A.E. Tekkaya. A review on hot stamping, journal of Materials Processing Technology, 210 (2010)2103-2118
2. Yisheng Zhang, Zijian Wang, Liang Wang. Progress in hot stamping process and equipment for high strength steel sheet. Journal of Plasticity Engineering, 2018, 25(5): 11-23.
3. Y. ZHANG, Y. WANG, B.ZHU, Y. LIU, etc. Research progress of hot stamping technology based on multi part integration. Journal of Plasticity Engineering,2023,30 (8): 1-7
4. MALLEN R Z． RIGGSBY J． 2014 Acura MDX one-piece hot stamp door ring development Global Powertrain Congress，2013
5. Gokhale Nachiket, Tandon Gagan. Ulti Part Integration™ concepts using Press Hardened Steel Laser Welded Blanks (MPI) - U-Frame Concept,2022 International Automotive Body Congress, IABC 2022.
6. H. Pan, K. Ding, Y. L. Gao, T. H. Wu. Performance Evaluation and Application of the Laser Welded Joint with Filler Wire for Al-Si Coated Press-Hardened Steels, Proceedings of the 6th International Conference on Advanced High Strength Steel and Press Hardening (ICHSU 2022), Atlantis Press,2023:185-194. DOI 10.2991/978-94-6463-114-2_25.