Simulation-based study of hot forming for dual door rings through LS-DYNA

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Car door rings play a crucial role in ensuring the safety and comfort of vehicles. Traditional cold forming methods used in manufacturing these components often encounter challenges related to complexity and inefficiency. This study aims to investigate the feasibility and advantages of employing hot forming technology for producing dual door rings, with a focus on overcoming the limitations associated with conventional forming techniques. A comprehensive simulation model was developed for the hot forming process of dual door rings, taking into account material properties, geometric configurations, and process parameters. The simulations were performed using LS-DYNA software, which utilizes a combination of explicit and implicit methods to provide a detailed analysis of the hot stamping process. Key process parameters such as forming temperature and pressure were systematically varied to assess their influence on the quality of the formed components. The study successfully achieved one-time forming of dual door ring parts using billets of different thicknesses and various hot stamping-formed steels. Based on the simulation results, the structural design of the dual door ring was optimized, resulting in an enhanced and efficient hot forming process flow. Hot forming technology, coupled with appropriate parameter optimization, effectively addresses the manufacturing challenges associated with dual door rings.

Keywords: Dual door rings; Hot forming; Simulations; LS-dyna; Process optimization.

1. Introduction

In the pursuit of improved fuel efficiency and reduced emissions, the automotive industry is increasingly turning to lightweight materials and advanced manufacturing techniques [1]. Hot stamping technology enables rapid formation of complex parts, while ensuring forming accuracy, reduced weight, and increased strength [2]. The application of hot stamping in automotive industry includes chassis components, like A-pillar, B-pillar, bumper, roof rail, rocker rail and tunnel [3]. Hot stamping is widely used in automobile manufacturing, particularly in the forming production of integrated door rings, which is a key technology [4]. Door rings are crucial structural elements that encase the vehicle's door frame, playing a vital role in absorbing impact energy during a collision and safeguarding passenger safety. As vehicle designs become more intricate and safety standards more stringent, the manufacturing of integral door rings necessitates the design of structural components with varying thicknesses and strength requirements for different sections [5]. Current research and manufacturing of automotive door ring components mainly focus on individual door rings [6] However, research on hot forming manufacturing of double door rings is relatively limited, and there is a lack of precise guidance in industrial production.

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This study aims to investigate the feasibility and advantages of hot forming technology for dual door rings, with a focus on overcoming the limitations associated with traditional forming methods. By creating a simulation model using the LS-DYNA software, this research aims to examine the effects of critical process parameters like forming temperature and pressure on the quality of the formed parts. The objective is to establish an effective hot forming process flow that optimizes the structural design of dual door rings, thereby enhancing their performance and ease of manufacturing.

2. Simulation Modeling of Hot Forming for Dual Door Rings

2.1. *Establish material model cards*

To meet the performance requirements of each part of the dual door ring component, four types of hot-forming steel were selected and welded together to form a complete daul door ring blank. Use MAT106 and MAT-T01 thermal material cards of LS-dyna software to establish material model. The stress-strain curves of materials at different temperatures and strain rates can be defined through the MAT106 card. The thermal parameters of the material are listed in Table 1. Define in the material card of the true stress-strain curves for $0.001\,s^{-1}$, $0.01\,s^{-1}$, $0.1\ s^{-1}$, $1\,s^{-1}$ and $10\ s^{-1}$ at different temperatures from room temperature (20 °C) to 850 °C.

Table 1. Thermo-physical properties parameters.

Specific heat [mJ/mm3K]	Thermal expansion [1/K]	Heat conductivity [W/mK]
4.37	1.3×10^{-5}	32

2.2. *Design stamping models and blanks*

The part diagram of the dual door ring designed by CATIA is shown in Figure 1 (a). The dual door ring component includes A-pillar, B-pillar, C-pillar, threshold beam, and roof side beam. The original blank is welded from 11 plates of different thicknesses (0.9-2.0mm) and strength (550~1800MPa) (Figure 1 (b)). Use Hypermesh to create mesh files with the size of 5mm element for the blank, punch and die molds. Figure 1 (c)shows the model design for hot stamping process.

2.3. *Hot stamping process settings*

The parameters for hot stamping simulation are as follows: forming temperature of 800 °C, stamping speed of 100 mm/s, initial mold temperature of 50 °C, and friction coefficient of 0.35. During stamping, the die remains stationary, and the blank is formed through the upward movement of the binder and punch. The hot stamping simulation is divided into three parts: stamping forming, holding pressure, and spring-back analysis. Stamping forming and holding pressure are defined using explicit analysis in LS-DYNA software, followed by implicit analysis of spring-back after completing the display analysis.

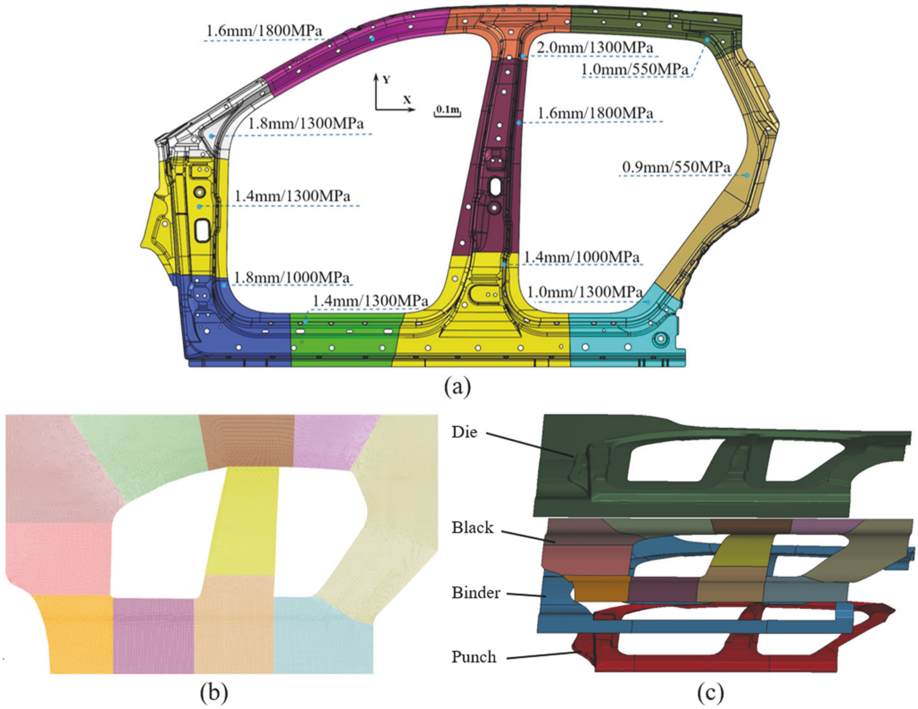

Fig. 1. (a)The part diagram of the dual door ring, (b)Elements model of Blank, (c)Model design for hot stamping process.

3. Results and Discussion

Figure 2 presents the simulation results of the hot stamping forming process for dual door rings. Overall, the forming performance of the door ring components is acceptable, with the majority of the parts experiencing a thickness reduction of less than 15%. However, several issues were identified in the simulation, particularly in regions subjected to high forming angles, where an excessive thickness reduction is noted (highlighted in the circular box in Figure 2). Moreover, material flow during the forming process leads to a tendency for sheet stacking at the corners, as indicated in the square box in Figure 2. Figure 3 further elucidates the problem of significant thickness reduction at the corner positions of the A-pillar and C-pillar. Notably, the C-pillar exhibits a thinning rate exceeding 50%. This substantial reduction in thickness is likely attributed to the severe forming angles, approaching 90°, resulting in unfavorable forming outcomes and compromised structural integrity of the material. To mitigate these issues, several strategies can be employed. Adjusting the geometry of the parts to reduce the forming angles can significantly decrease the rate of thickness reduction. Alternatively, applying localized reinforcements or patches in areas prone to excessive thinning can enhance mechanical performance and distribute the forming stresses more evenly. Additionally, wrinkling observed at the edges of the parts can be addressed by modifying the forming process parameters. Increasing the pressure applied by the edge pressing ring can help minimize wrinkling by providing better material restraint during the forming operation. Furthermore, altering the initial shape of the sheet metal, such as optimizing its contour to accommodate the forming process, can also reduce the occurrence of edge wrinkles.

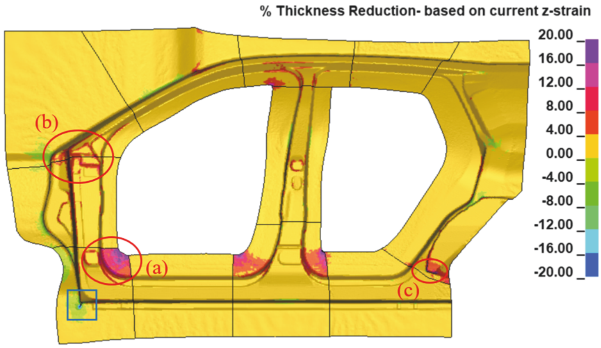

Fig. 2. Thickness reduction distribution of dual door rings.

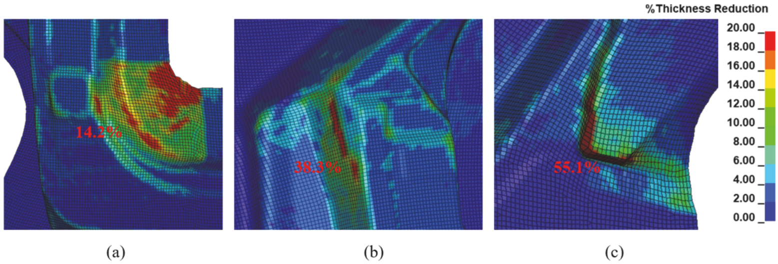

Fig. 3. Location with excessive thickness reduction, (a) A-pillar, (b) A-pillar, (c) C-pillar.

4. Summary and Suggestions

In this study, the hot forming process of the integrated dual door ring was investigated and simulated using LS-DYNA. The key findings can be summarized as follows:

A simulation model was developed for the hot stamping forming of dual door rings and material cards, and the forming of integrated dual door ring parts was simulated. By considering resource conservation, the reliability of the double door ring parts was analyzed, production efficiency was improved, and suggestions for enhancing the design of the double door ring parts were provided.

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