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Application of Cold Stamping Process with 1500 MPa Ultra-High-Strength Steel for Aftermarket Bumper

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Abstract. With the advancement of lightweight vehicle structure design, the demand for hot-stamped steel in the aftermarket (AM) sector has steadily increased. However, Taiwan's production capacity has been limited to two hot stamping lines, insufficient to meet the growing demand for hot-stamped AM body panels. To address this issue, cold stamping processes using 1500 MPa ultra-high-strength steel have been investigated as an alternative to enhance production capacity. In this study, the Yoshida-Uemori (Y-U) model was developed for 1500 MPa steel through tensile-compression tests to characterize its Bauschinger effect and work hardening behaviour. The model's accuracy in predicting springback was validated via U-shaped panel stamping tests. The feasibility of converting a hot-stamped AM bumper to one manufactured with 1500 MPa steel was evaluated through numerical simulations incorporating the validated Y-U model, followed by experimental trials. The results demonstrated that the cold-stamped bumper met dimensional accuracy and performance standards, as verified through CAPA certification, confirming the potential of cold stamping as a viable alternative to traditional hot stamping for AM bumper production.

Keywords: Cold Stamping; Ultra-High-Strength Steel (UHSS); Numerical Analysis; Springback

1 Introduction

The COVID-19 pandemic has resulted in extended vehicle lifespans and increased maintenance demands globally, leading to a significant rise in the demand for the aftermarket (AM) sector. Taiwan, as a major supplier of AM body panels, contributes over 80% of the global market share and holds a critical position in the global supply chain.

As lightweight vehicle design advances, demand for 1500 MPa boron steel in the AM sector has increased [1]. However, Taiwan's production is limited to two hot stamping lines. To overcome this, manufacturers are exploring cold stamping with 1500 MPa ultra-high-strength steel to expand capacity and meet market demand. With growing emphasis on carbon reduction and carbon taxes, the environmental impact of hot stamping is under scrutiny. The process requires heating above 900°C, with the heating phase alone contributing approximately 91% of total carbon emissions [2]. Consequently, cold stamping of ultra-high-strength steel is emerging as a viable alternative, offering lower energy consumption and reduced emissions.

In this study, the Yoshida-Uemori (Y-U) model was developed for 1500 MPa ultra-high-strength steel through tensile-compression tests to characterise material behaviour [3]. The feasibility of converting a hot-stamped AM bumper to a cold-stamped 1500 MPa ultra-high-strength steel bumper was evaluated. Numerical simulations, based on the Y-U model, guided cold stamping process design and die surface compensation. Experimental trials further validated the process, demonstrating that the cold-stamped bumper, after CAPA certification, met dimensional accuracy and performance requirements, confirming its viability as an alternative to hot-stamped AM bumpers.

2 Development of Bumper Process

2.1 Material

A boron steel 22MnB5 AM front bumper with a thickness of 1.6 mm and dimensions of 1401.6 mm × 143.6 mm × 131.7 mm, as shown in Fig. 1, was designated for material transition to 1500 MPa martensitic steel MS 1500 (supplied by China Steel Corporation, CSC). The ultimate tensile strength and elongation of MS 1500 are 1538 MPa and 7.4%, respectively.

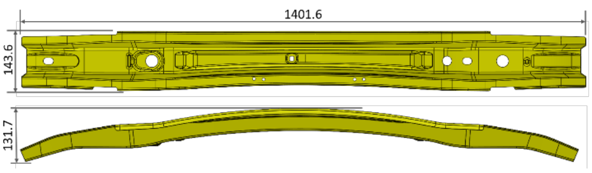

Fig. 1. 3D Model of AM front bumper

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2.2 Simulation of the cold forming process for MS1500 AM front bumper

Numerical finite element (FE) simulations of the MS1500 AM front bumper were conducted in PAM-STAMP using the Y-U model (Fig. 2), which was developed based on tensile-compression cyclic tests to optimize the forming process design. Additionally, the model was employed to compensate for the designed forming die surface, ensuring the dimensional accuracy of cold-formed parts.

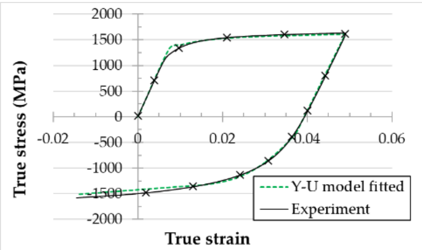

Fig.2. Comparison of fitted Y-U model and experimental results

A two-step crash forming process (Fig. 3) was selected based on the material's formability characteristics to achieve an optimal balance between springback reduction and tooling cost efficiency. In the first step, a preforming die with an enlarged corner radius was designed to enhance material flow and reduce localised strain concentration. In the subsequent second step, the preformed part was shaped to its target geometry. The approach effectively minimised tensile stress gradients along the thickness direction at the corner radius, thereby suppressing springback effects

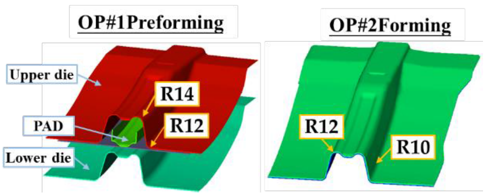

Fig. 3. Two-step forming process design

Fig. 4 illustrates the predicted dimensional accuracy of the formed parts with and without die surface compensation. The results demonstrate that applying compensation to the die surface in the second stage of the forming process effectively suppressed the springback effect, thereby improving the overall forming accuracy.

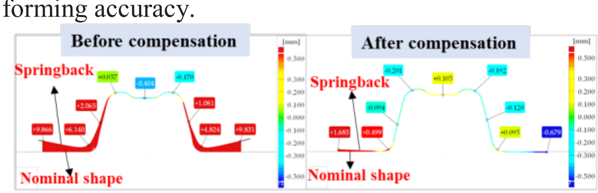

Fig. 4. Comparison of predicted dimensional deviation with and without compensation

3 Product Verification

The forming die was designed using FE-analysis-compensated die surfaces, and the two-step forming process for the MS 1500 AM front bumper was successfully completed through prototyping on a 1000-ton hydraulic press. The formed part exhibited no wrinkles or fractures, as shown in Fig. 5.

Fig.5. The cold forming results of MS 1500 AM front bumper

To commercialise the MS 1500 AM front bumper in the AM market, CAPA501 certification requirements must be met. This process involves assembling the MS1500 AM front bumper with other bumper components and subjecting it to dynamic impact testing, which simulates a vehicle collision at 8.05 km/h. The impact resistance and appearance defects must be equivalent to those of the boron steel AM front bumper. Fig. 6 presents the results of the dynamic impact test on the MS 1500 and boron steel AM front bumpers. The results indicate that the dents and damaged areas were identical to those of the boron steel AM front bumper. In addition to satisfying the dynamic impact test conditions, the dimensional accuracy of the MS1500 AM front bumper has also met the target requirements of CAPA501. Consequently, it has obtained CAPA certification in the United States.

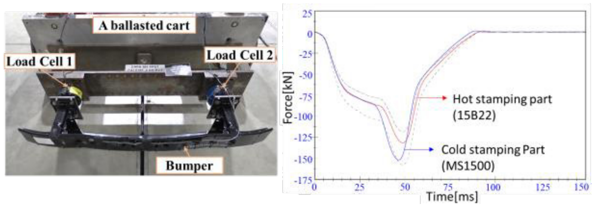

Fig. 6. Results of the frontal collision test

4 Conclusions

A manufacturing approach that replaces the hot stamping process of boron steel with a cold stamping process using MS 1500 steel for producing AM front bumpers was proposed in the study. A dynamic hardening material model was developed through tensile-compression tests, enabling effective forming process design and die surface compensation to mitigate springback. The product achieved CAPA501 certification, confirming performance comparable to boron steel AM parts. This process offers carbon reduction benefits and presents an innovative solution for Taiwan's automotive parts industry, highlighting the potential of cold stamping technology in the global aftermarket.

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