The Development of Hot Forming 7075 High Strength Aluminum Door Impact Beam

CHENG-KAI CHIUHUANG* and CHUNG-YI YU**

**Iron & Steel Research & Development Department*
***New Materials Research & Development Department*
China Steel Corporation

In recent years, the issue of global warming has gained more attention, and countries are gradually implementing stricter regulations on vehicle carbon emissions. As a result, lightweight design has become a crucial trend in the automotive industry. Vehicle design now needs to simultaneously achieve both lightweight and enhanced safety. Besides the use of high-strength steel, aluminum alloy components, due to their low density and lightweight characteristics, are increasingly being integrated into vehicle designs. This trend is even more pronounced in electric vehicles. To improve the poor ductility of high-strength aluminum alloys at room temperature, the development of warm forming and hot forming technologies for aluminum alloys has been advanced. This study primarily investigates the feasibility and performance of hot forming 7075 high-strength aluminum alloy material into the car door impact beam. Utilizing computer simulation analysis and actual die tryout, the research results can serve as reference cases for the industry when incorporating high-strength aluminum alloy parts in future designs.

Keywords: Lightweight, Electric vehicle, Hot forming, High-strength aluminum

1. INTRODUCTION

In response to the rising awareness of environmental protection and energy conservation, countries are progressively tightening vehicle carbon emission standards to reduce fuel consumption and CO_2 emissions. Lightweighting has become a current trend in the automotive industry. Compared to steel, aluminum alloys have a lower density, which contributes to their lightweight characteristics, and they are gradually being incorporated into vehicle design. In recent years, international research institutes and the industry have been developing hot-forming processes for high-strength 6xxx/7xxx aluminum alloys(1). The aim is to increase the forming temperature of the materials to enhance their ductility(2).

The concept of aluminum alloy hot forming (HFQ, Hot Forming, and Quenching) was first proposed by Professor Jianguo Lin at Imperial College London(3). The aluminum alloy materials generally used in hot-forming processes are O-temper or F-temper alloys. In a stamping plant, these materials are first heated in a furnace to a temperature between 450-580°C for solution heat treatment to form a super-saturated solid solution microstructure with a homogeneous single phase. After heating, the blank is transferred into a cold die, where it is pressed into complex shapes and held for a few seconds to ensure rapid cooling, or quenching. This process aims to prevent the formation of precipitates in the microstructure, maintaining a supersaturated solid solution microstructure. Since the formed sheets lack sufficient strength, they require aging treatment within the plant for 6-24 hours to enhance the strength of the parts. Compared to the conventional cold stamping process, the hot forming process is advantageous in reducing tool wear, extending tool life, and minimizing spring back(4).

This paper uses an automotive door impact beam as the research target. Through CAE analysis, it compares the three-point bending performance of the original 15B22 boron steel design and 7075 high-strength aluminum alloy design to evaluate the lightweight benefits achievable by adapting the aluminum hot forming process. By conducting actual die development and stamping trials, the feasibility of forming 7075 aluminum alloy car door impact beams using the hot forming process and the performance of the resulting products are examined. The findings of this study can serve as a reference for the industry in incorporating high-strength aluminum alloy parts in vehicle design.

2. EXPERIMENTAL METHOD

This study first optimizes the geometric design of the manganese boron steel car door crash beam version (Fig.1) to facilitate the switch to 7075 aluminum alloy material. This involves increasing the width of the mid-section load-bearing area to enhance bending rigidity and enlarging the R radius at the bottom of the grooves to improve formability and energy absorption. The optimized model undergoes CAE simulation analysis using PAM-STAMP software (Fig.2), demonstrating no wrinkling or rupture risks of the material after stamping, with a maximum thinning rate of 13.8%. In general industry practice, the maximum allowable thinning rate standard is 20%. The die material used is SKD61, heat-treated to a hardness of HRC52-54, and die tryouts are conducted using an 800-ton hydraulic press.

The chemical composition of the 7075-F alloy used in this study is shown in Table 1. In the part manufacturing phase, the 7075-F (t=2.8mm) flat plate is first placed into a heating furnace. The plate remains in the furnace for 800 seconds at a temperature of 490 °C. After exiting the furnace, an automated arm transfers the plate to a die coated with graphite lubricant. Upon die closure, the part is pressed with a force of 300 tons for 15 seconds before opening to remove the part (Fig.3). Subsequently, the part is placed into an oven for artificial aging at two different conditions: 120°C for 6 hours and 120°C for 24 hours. Following this, laser cutting is used to obtain

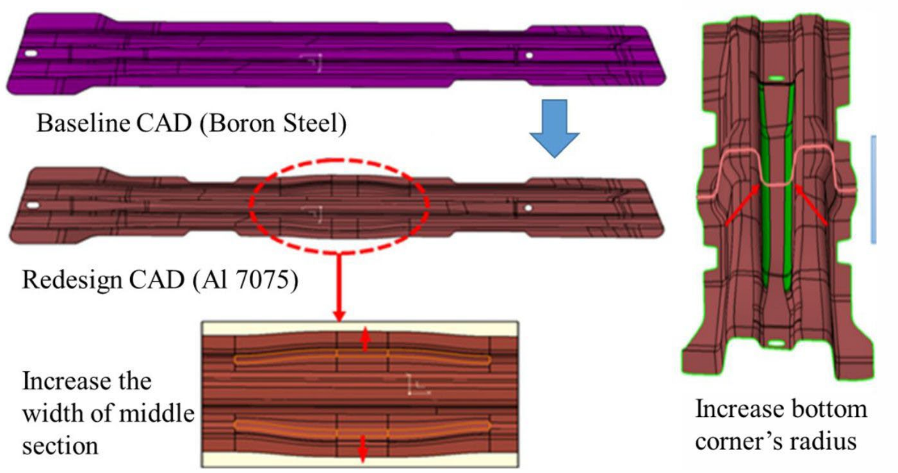

Fig.1. Redesigned CAD model of aluminum door impact beam.

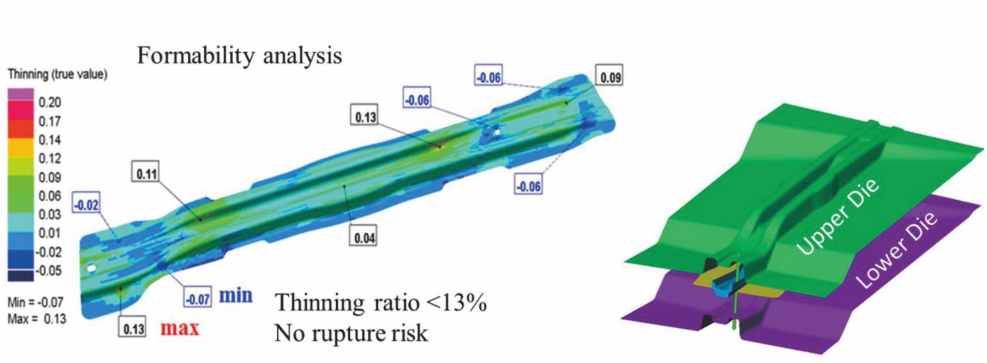

Fig.2. CAE model for the formability check.

Table 1 Chemical compositions of 7075 aluminum alloy (in wt%).

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
Wt.%	<0.4	<0.5	1.2-2.0	<0.3	2.1-2.9	0.18-0.28	5.1-6.1	<0.2

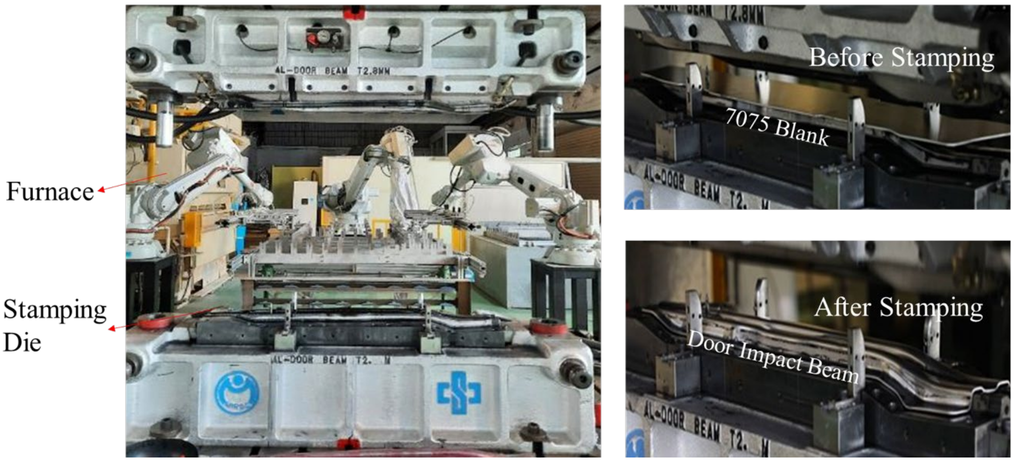

Fig.3. Stamping die for the 7075-door impact beam hot forming.

tensile test specimens from different locations on the part. These specimens undergo baking at 185°C for 20 minutes to simulate aging conditions during factory painting, followed by tensile testing to assess mechanical performance. Additionally, three-point bending tests (Fig.4) were conducted on parts subjected to different aging conditions to compare the bending performance of the 7075 car door impact beams with those made of 15B22 steel. Simultaneously, section thinning rates of the aluminum car door impact beams were measured to validate the CAE simulation results.

3. RESULTS AND DISCUSSION

3.1 The Simulation Results of the Three-Point Bending Performance of 7075 and 15B22 Door Impact Beam

After optimizing the geometric shape of the door impact beam section, computer-aided engineering (CAE) simulations were used to compare the three-point bending performance of the original hot stamping 15B22 boron steel (1.4mm) and different thicknesses of hot-formed 7075 aluminum alloy. The simulation results shown in Fig.5 indicate that using 2.8mm thick 7075 aluminum alloy can achieve the performance level of the original 1.4mm thick 15B22 boron steel. As shown in Table 2, the maximum punch reaction force for the 7075 version is 18.1kN, slightly lower than the 18.5kN of the 15B22 version. The energy absorption of the 7075 version is 2125J, which exceeds the 1869J of the 15B22 version, where energy absorption represents the total area under the curve. Switching from the original 15B22 to 7075 for the car door impact beam reduces the weight from 1.866 kg to 1.236 kg, achieving a weight reduction benefit of 33.8%.

Fig.4. Schematic of three-point bending test.

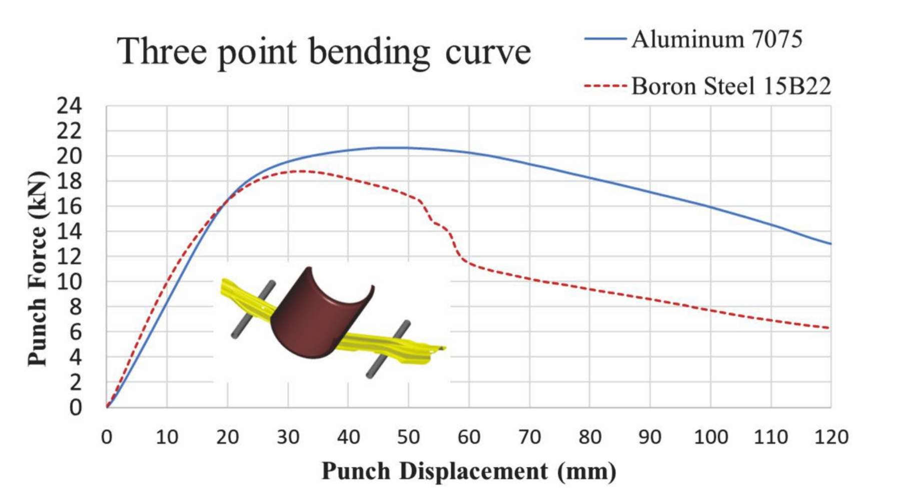

Fig.5. Simulation results for the aluminum 7075 and boron steel 15B22 three-point bending test.

Table 2 CAE simulation results for the punch reaction force and energy absorption of 15B22 and 7075 door impact beams.

Material	Thickness (mm)	Maximum Punch Reaction Force (kN)	Energy Absorption (J)	Weight (kg)
Hot Stamping Boron Steel 15B22	1.4	18.5 (100%)	1869 (100%)	1.866 (100%)
Hot Forming Aluminum Alloy 7075	2.8	18.1 (97.8%)	2125 (113.6%)	1.236 (66.2%)

3.2 Mechanical Properties of 7075 Door Impact Beam

The successfully formed car door impact beam parts are shown in Fig. 6. During the trial process, it was found that without applying graphite lubricant to the die, the high friction coefficient between the sheet and the die would cause the parts to crack during forming. Tensile test specimens were laser-cut from the parts and subjected to artificial aging treatment under two different conditions: 120℃/6hr and 120℃/24hr. As shown in Table 3, The tensile test results showed that the yield strength (YS) and tensile strength (TS) of the 7075 hot-formed parts after 24 hours of artificial aging were higher than those after 6 hours of artificial aging. The average YS of the 6-hour aging specimens was 485 MPa, and the average TS was 556 MPa. For the 24-hour aging specimens, the average YS was 494 MPa, and the average TS was 560 MPa. The elongation between the 6-hour and 24-hour aging conditions showed no significant difference, with both averaging 10.2%.

In the observation of thickness reduction, CAE predictions of thinning and thickening locations correspond well with experimental trends. As shown in Fig.7, CAE simulations demonstrate a reliable prediction of material thinning during aluminum alloy hot forming, serving as a valuable tool to assess potential fracture occurrence during actual stamping and thereby reducing tooling modification costs.

Fig.6. Hot forming 7075 door impact beams.

3.3 Experimental Results of Three-Point Bending Test

The three-point bending test results (Fig.8) show that due to the optimized design of the part's cross-sectional shape, the maximum load of the 7075 hot-formed parts is greater than that of the original 15B22 manganese boron steel version (Table 4). The door beam with

Table 3 Mechanical properties of hot forming 7075 door impact beam.

Condition	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
Artificial Aging (120°C/6hr)	485	494	10.2
Artificial Aging (120°C/24hr)	556	560	10.2

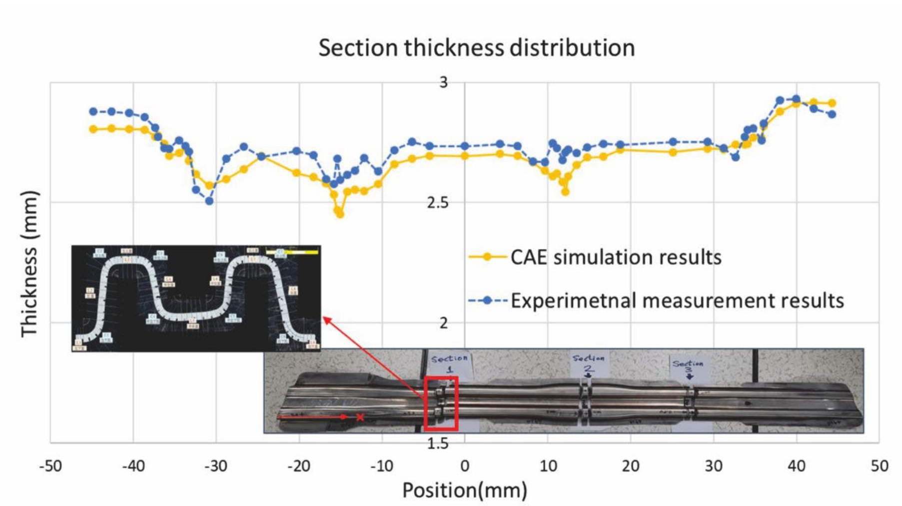

Fig.7. Simulation and experimental results of door impact beam's section thickness.

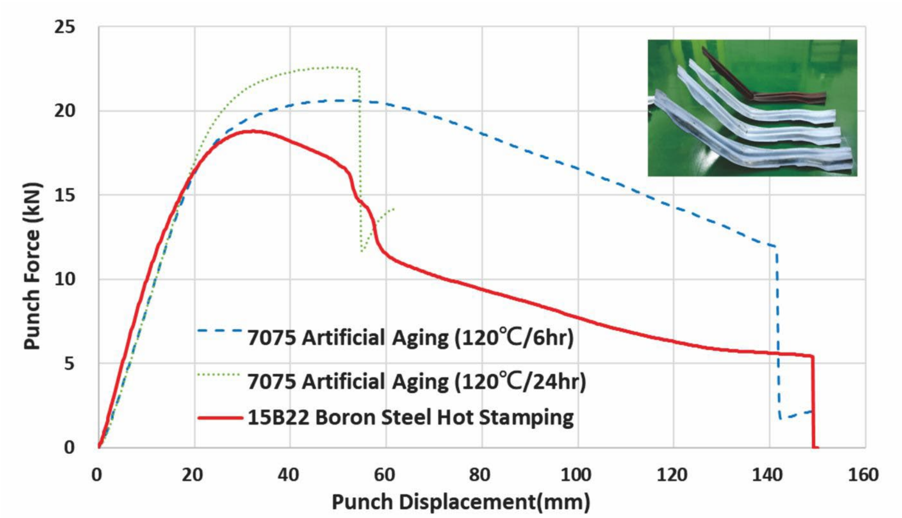

Fig.8. Three-point bending experimental results for the 15B22 and 7075 door impact beams.

6-hour artificial aging successfully pressed down to 150 mm, with a maximum punch load of 20.6 kN and energy absorption of 2310 J, which is better than the boron steel door impact beam's maximum load of 18.7 kN and energy absorption of 1556 J. For the door impact beam with 24-hour artificial aging, the maximum load increased to 22.5 kN. However, the door beam experienced fracture during the punch pressing process and stopped at around 55 mm of punch travel, with an energy absorption performance of only 1002 J. The three-point

Table 4 Experimental results for the three-point bending performance of 15B22 and 7075 door impact beams.

Material	Maximum Punch Reaction Force (kN)	Energy Absorption (J)
Hot Stamping Boron Steel 15B22	18.7 (100%)	1556 (100%)
Hot Forming-Aluminum Alloy 7075 Artificial Aging (120°C/6hr)	20.6 (110.1%)	2310 (148%)
Hot Forming- Aluminum Alloy 7075 Artificial Aging (120°C/24hr)	22.5 (120.3%)	1002 (64.3%)

bending results indicate that the artificial aging treatment time for the 7075 car door impact beam is recommended to be 120°C/6hr. If the 120°C/24hr artificial aging condition is used, the excessive strength of the parts during the deformation process may cause cracking, thereby reducing the energy absorption performance.

4. CONCLUSIONS

1. The results of this study indicate that using high-strength 7075 aluminum alloy indoor impact beams offers lightweight benefits, aiding automotive manufacturers in reducing carbon emissions. With optimal hot forming process parameters, the tensile strength (TS) of 7075 door impact beams can exceed 490 MPa after aging at 120°C for 6 hours and 560 MPa after aging at 120°C for 24 hours. Compared to the original 15B22 manganese boron steel version, the 7075 aluminum alloy version demonstrates increased energy absorption and a 33.8% improvement in lightweight advantages.
2. There is no fixed standard for choosing between the hot stamping process of 15B22 manganese boron steel or the hot forming process of 7075 high-strength aluminum alloy. This study found that the section-optimized design of 7075 door impact beams outperforms 15B22 in terms of bending resistance and energy absorption capability. However, with further optimization, the performance of the 15B22 version could also potentially surpass that of the 7075 version. Overall, the application of 7075 aluminum alloy offers advantages in weight reduction design, while the 15B22 steel version excels in cost and production efficiency. The choice between these options should depend on the car manufacturer's prioritization of the part's performance, weight, and cost considerations.

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