E. Lightweight Front Structures

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Objectives

- Benchmark, develop, and document proven solutions that will balance the interaction of material, manufacturing, and performance. The initial phase of the study focused on the automotive front-end system solutions that address high-volume manufacturing and assembly. Furthermore, example solutions were manufactured, and physical testing was performed to evaluate the advanced high-strength steel (AHSS) designs.
- Provide choices and consequences via the AHSS solutions that address real world challenges faced in the vehicle development process. A comprehensive knowledge-base design tool was developed to capitalize on a set of robust AHSS automotive design guidelines relating choices to consequences.

Approach

- Retrofitted an existing front rail system from a donor vehicle with AHSS dual-phase (DP) 800 to save 22% mass. In addition, a front bumper made from DP 980 replaced the existing bumper.
- Manufactured and tested the AHSS designed rail system and bumper to compare performance with the conventional design it replaced.
- Carried out analytical and physical testing on both the original and the redesigned rail system.
- Draw comparisons and document recommended practices.

Accomplishments: Additional Phase 2 Deliverables

- Provided team selection of stamped design.
- Obtained final optimized stamped rail and bumper designs.
- Completed formability simulation of the stamped design.
- Generated computer-aided design (CAD) data for manufacturing of the new stamped rail and bumper designs.
- Developed prototype tools for manufacturing rails and bumper stampings.
- Manufactured prototype dies for rails, rail extensions, and bumper.
- Developed new welding schedules for AHSS joining.
- Used static/dynamic stiffness design of experiment (DoE) finite-element (FE) models.
- Examined static stiffness DoE response surface.
- Examined dynamic stiffness DoE response surface.
- Stamped rails and bumpers and welded as assemblies.
- Prepared donor vehicle to receive the new rails and bumper.
- Welded new AHSS rails and bumper and installed into the vehicle.
- Conducted a successful (certified) Insurance Institute for Highway Safety (IIHS) 35-mph crash test of the retrofitted vehicle and recorded the results.

Future Direction

- Compare correlation of the vehicle crash (test) data with analytical results.
- Update Proteus, a knowledge base tool, with the findings of this project.
- Publish a final report detailing all of the findings of this project, including lessons learned.
- Complete roll-out application methodology communications package.

Phase 2 Summary (October 2003 through September 2004)

The project team selected the concept 2 stamped design for the final vehicle build. This stamped design consisted of octagonal Dual-Phase (DP) 780, three-piece, tailor-welded rail inner and rail outer stampings with symmetric flanges and tapered front section. This concept included a three-piece tailor-welded rail extension design with reinforcement. The rail curvatures were modified in side (XZ) and plan (XY) views. The original bumper from the donor vehicle was replaced with a DP980 two-piece double-box design incorporating energy-absorbing features.

Selection of Concept for Final Design

A comparison of the stamped design from concept 2 and the hydroformed design from concept 3 was prepared to select the most suitable design that could then be further optimized for mass reduction. A table detailing the comparison of the two designs appears as Table 1.

Although the hydroformed design had the potential for more mass savings, the stamped design provided the option with less manufacturing concerns and a higher chance for acceptance in the production environment. The team thus selected the stamped design for further development and prototyping. The final optimization determined the steel grades and gages of the rail design as shown in Table 2.

Table 1. Design comparison—stamped vs hydroformed rails

	Stamped design	Hydroformed design
Mass reduction	31%	31%
Performance	NCAP meets target, and IIHS performance did not meet the target, but the team felt that this could be achieved	NCAP meets target and acceptable IIHS performance
Manufacturing	— Use of tailor-welded blanks well established — Tailor-welded blanks can complicate stampings — Springback is a major issue — Small holes can be a problem	— Manufacturing tailor-welded tubes could be an issue — Prebending and hydroforming tailor-welded tubes could present significant problems — Springback is controllable — Small holes can be a problem
Assembly	— Welding DP980 with DP980 could be an issue — Spot welding rails to attached parts is not an issue	— No assembly welding required — Single-sided welding of rails with attached parts would be problematic
Production	Acceptance of stamped design in production environment is not an issue	Acceptance of hydroformed design in production environment is difficult

Table 2. Final stamped rail design optimization

Components	Baseline		Optimized	
	Grade	Gauge	Grade	Gauge
Bumper beam	DP980	1.0	DP980	1.0
Rail front outer	DP800	1.0	DP800	1.0
Rail front inner	DP800	1.0	DP800	1.0
Rail mid-outer	DP800	1.4	DP800	1.2
Rail mid-inner	DP800	1.4	DP800	1.2
Rail rear outer	DP800	2.0	DP800	1.4
Rail rear inner	DP800	2.0	DP800	1.4
Rail extension front	DP800	2.0	DP800	2.0
Rail extension rear	DP800	1.3	DP800	1.2
Rail extension reinforcement	DP800	2.0	DP800	1.4
Rail inner reinforcement	DP800	2.0	DP800	2.0
Total mass		34.460		30.458
Mass reduction (kg)		4.77		8.77
% Mass reduction		12.16		22.36

Formability Simulation of the Final Stamped Design

Formability simulations were conducted for the bumper and rail subassemblies. Bumper formability analyses were undertaken for the two-piece DP980 double-box design with incorporated energy-absorbing features. Both the inner and outer bumper components showed thinning below the target of 11%, thus indicating that the bumper is a formable design. The formability analysis results for the bumper components are shown in Figures 1 and 2.

The rail extension was fabricated using a three-piece tailor-welded DP780 design. The rail

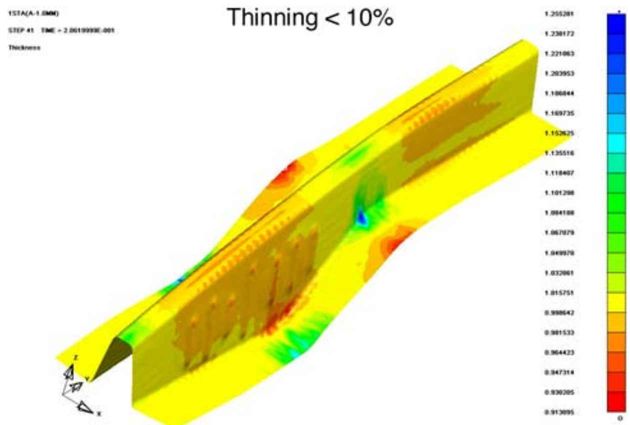

Figure 1. Bumper inner thinning.

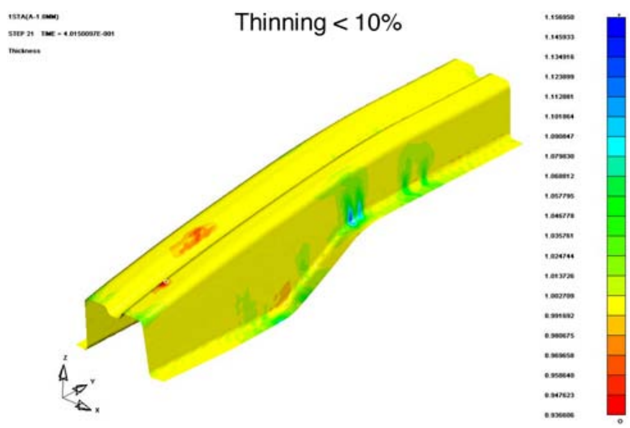

Figure 2. Bumper outer thinning.

extension reinforcement was also designed using DP780 steel. The rail extension and the rail extension reinforcement yielded a thinning of 15% and 13%, respectively. The formability analysis results for each of these parts are shown in Figures 3 and 4. Although the actual thinning was greater than

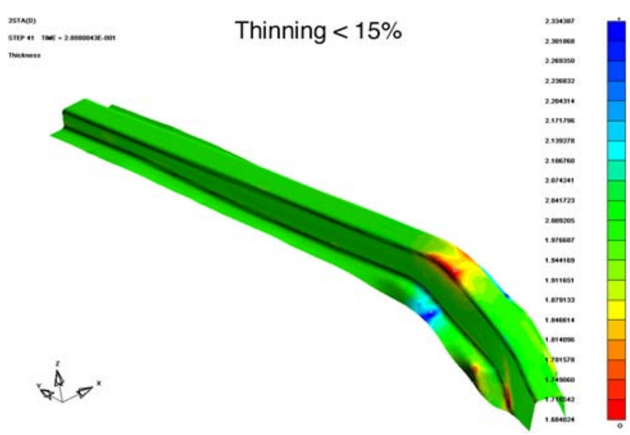

Figure 3. Rail extension thinning.

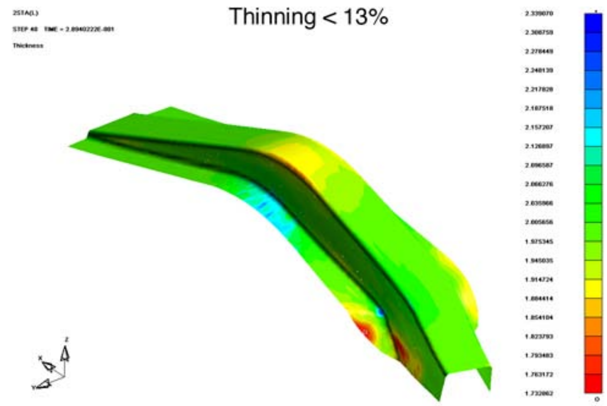

Figure 4. Rail extension reinforcement thinning.

the target of 11%, it was determined that the condition could be alleviated by rounding selected corners. The rail extension and the rail extension reinforcement were thus considered formable.

Generation of CAD Data

The computer-aided design (CAD) data for manufacturing the new rail and bumper system designs were generated, and the blank sizes of the components were also developed. These images appear as Figures 5, 6, and 7.

Development of Prototype Tools

The development of the required prototype tools for the rail and bumper subassemblies was completed and fabrication followed. Examples of selected tools and stamped parts follow as Figures 8 through 12.

Vehicle Retrofit/Reassembly

Following the fabrication and assembly of the front rails, rail extensions, and rail extension reinforcement, these and the bumper subassemblies were retrofitted onto the donor vehicle. It was also necessary to modify certain of the original donor vehicle mating parts to accommodate the new assemblies. Figures 13 through 15 depict select tooling as well as vehicle modifications.

Crash (Validation) Test

The New Car Assessment Program (NCAP) 35-mph Crash Test of the donor vehicle retrofitted with the AHSS rails and bumper was performed at the Transportation Research Center (TRC) in East Liberty, Ohio, on September 21, 2004.

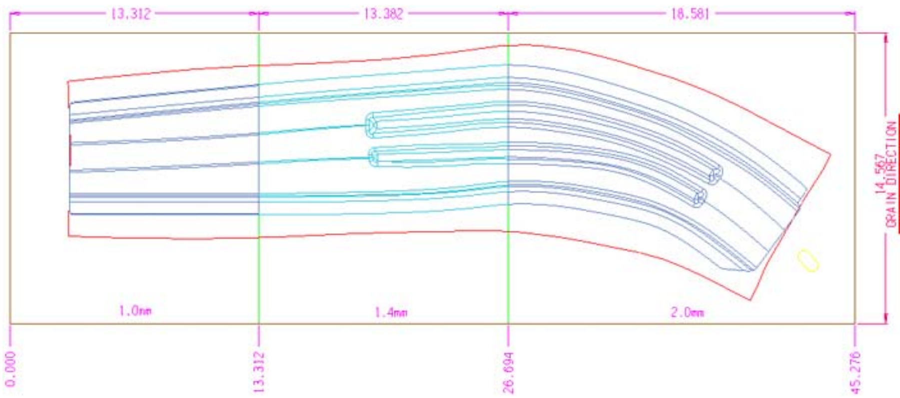

Figure 5. CAD-developed blank size for front rail outer.

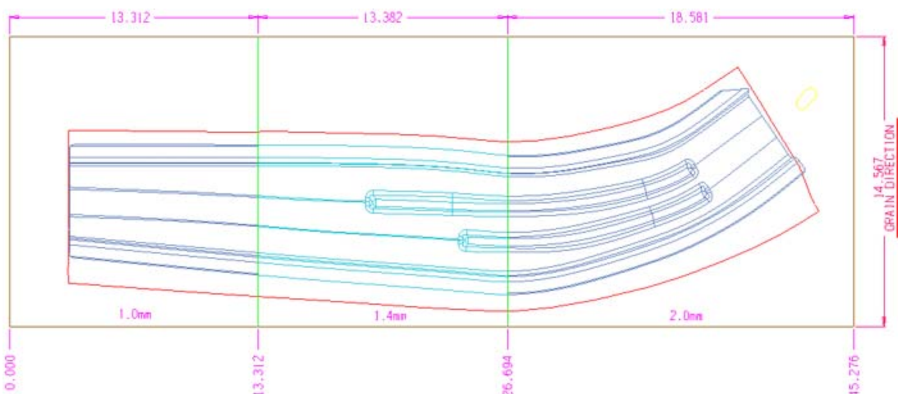

Figure 6. CAD-developed blank size for front rail inner.

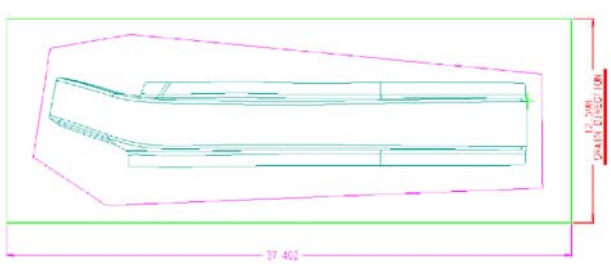

Figure 7. CAD-developed blank size for rail extension.

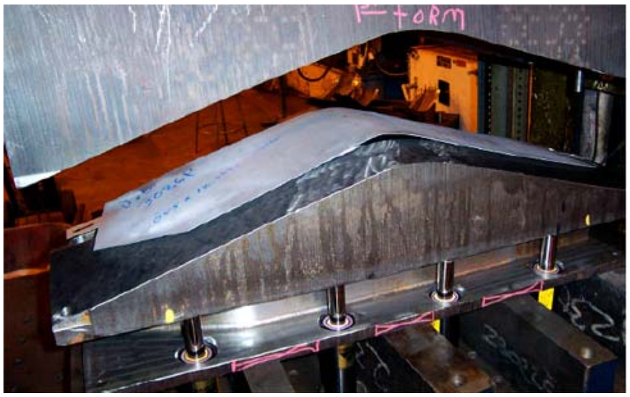

Figure 8. LH rail extension reinforcement—first form.

Figure 9. LH rail extension reinforcement—second form.

Figure 10. Formed LH rail extension reinforcement.

Figure 11. Bumper assembly fixture—combined.

Figure 12. Bumper assembly complete.

Figure 13. Complete rail assembled.

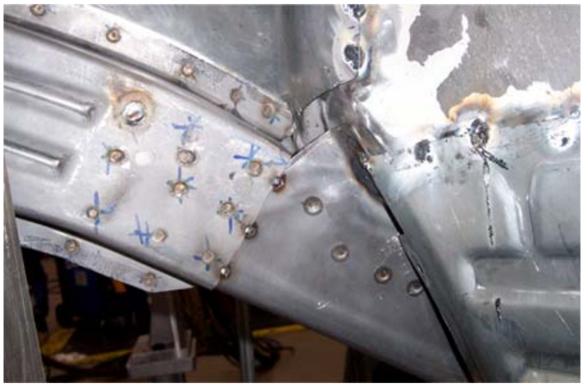

Figure 14. Weld connection between front rail and rail extension.

Figure 15. Custom parts fabricated, welded, and bonded as on the original vehicle.

Conclusions/Observations

Preliminary observations following the crash test indicated positive results were achieved (Figure 16). Only upon detailed analysis of the test data can specific conclusions be drawn. Final results are expected early in FY 2005, at which time the final project report will be completed.

Figure 16. Posttest three-fourths front view—right.