

Optimized AHSS Structures for Vehicle Side Impact

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ABSTRACT

Advanced high strength steels (AHSS) have been widely accepted as a material of choice in the automotive industry to balance overall vehicle weight and stringent vehicle crash test performance targets. Combined with efficient use of geometry and load paths through shape and topology optimization, AHSS has enabled vehicle manufacturers to obtain the highest possible ratings in safety evaluations by the Insurance Institute for Highway Safety (IIHS) and the National Highway Traffic Safety Administration (NHTSA). In this study, vehicle CAE side impact models were used to evaluate three side impact crash test conditions (IIHS side impact, NHTSA LINCAP and FMVSS 214 side pole) and the IIHS roof strength test condition and to identify several key components affecting the side impact test performance. HyperStudy® optimization software and LS-DYNA® nonlinear finite element software were utilized for shape and gauge optimization. Simplified bending crush simulation models were developed and a cross-section optimization was performed for bending crush performance. The optimized cross-sections were then applied to rocker reinforcement, B-pillar reinforcement, front seat cross-member, roof rail and door-beams to reduce the B-pillar and door-beam deformations during side impact crash tests. Finally, a material and gauge optimization was conducted on side structures using dual phase (DP) steels with 590 to 980 MPa minimum tensile strength. Mass savings was achieved without compromising the side impact crash test performance when AHSS and optimized cross-sections of the structural components were applied.

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INTRODUCTION

The increasing applications of AHSS and computer optimization technologies in automotive structural designs have enabled lightweighting with balanced vehicle crash test performance and functionality [1,2,3,4,5,6]. For example, optimized roof structures can meet the new FMVSS 216 roof crush standard without significantly increasing vehicle mass with the comprehensive usage of AHSS such as dual phase (DP) steels and hot-stamping boron steel [1-2]. The Auto/Steel Partnership's (A/SP) Future Generation Passenger Compartment project estimated that a potential mass savings of 15 to 20 percent could be achieved in a conceptual sedan when AHSS and design variations were selectively applied using structural optimization techniques [3-4]. The FutureSteelVehicle (FSV) program recently developed by WorldAutoSteel featured optimized AHSS body structures proposed for compact electrified vehicles in the 2015 to 2020 model-year using the similar optimization techniques [5].

The focus of this study is to optimize the cross-sections of components such as rocker reinforcement, B-pillar reinforcement, front seat cross-member, roof rail and door-beams with considerations of the side impact crash test performance and roof strength evaluation. As these components deform in a bending mode during side impacts, simplified bending crush simulation models were utilized in the cross-section optimization for a quick turnaround. The optimized cross-sections were then applied to these components in full vehicle crash simulation models for material and gauge optimizations to evaluate potential mass savings with AHSS and the optimized cross-sections. HyperStudy® optimization software and LS-DYNA® nonlinear finite element software were utilized together for the shape and gauge optimizations. The theory and details of using HyperStudy® and LS-DYNA® for cross-section optimization can be found in [6].

CRASH SIMULATION MODELS

The vehicle CAE model used in the current study was adopted from the model in Phase I of the A/SP Future Generation Passenger Compartment (FGPC) project [3]. In this study, the crash performance evaluation and the cross-section optimization were carried out for four test conditions, i.e., IIHS side impact, LINCAP side impact, FMVSS 214 new side pole impact and IIHS quasi-static roof strength. The details of the four crash events are described below.

IIHS SIDE IMPACT

The IIHS side impact test configuration is a moving deformable barrier (MDB) striking the driver side of a test vehicle perpendicularly at a speed of 50 km/hr (31 mph) [7]. The IIHS side impact model used in this study is shown in [Figure 1](#). The IIHS MDB model with solid elements developed by Livermore Software Technology Corporation (LSTC) [8, 9] was used in the analysis.

As a side impact dummy model was not considered in this study, only the structural performance based on B-pillar deformation measurements as prescribed in the IIHS test protocol was evaluated [7]. In the IIHS side impact, simulation results of the baseline model showed that the rocker, B-pillar and door-beams were key components controlling the B-pillar deformation as measured per IIHS's procedure.



Figure 1. IIHS side impact model

LINCAP SIDE IMPACT

The LINCAP (Lateral Impact New Car Assessment Program) side impact test program is administered by the NHTSA. LINCAP utilizes a MDB impacting the test vehicle at 62 km/hr (38.5 mph) in a 27-degree crabbed impact configuration. The LINCAP model used in this study is shown in [Figure 2](#). The MDB model with solid elements developed by LSTC [10] was used in the analysis. Again, the structural performance was evaluated based on the B-pillar deformation since the side impact dummy model was not included in the analysis. In the LINCAP side impact, simulation results of the baseline model showed that the

rocker and B-pillar were key components controlling the B-pillar deformation as evaluated in this study.

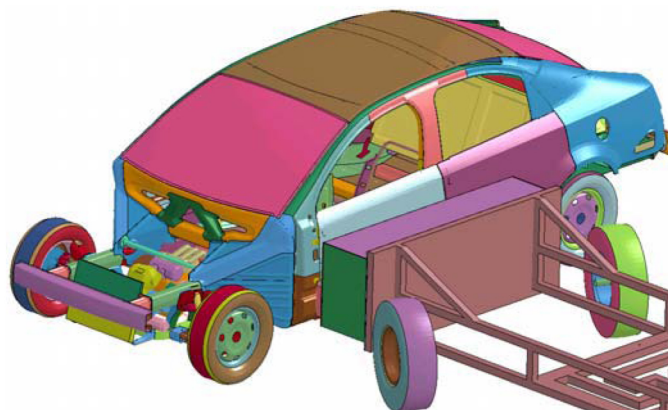


Figure 2. LINCAP side impact model

SIDE POLE IMPACT

The FMVSS 214 side pole impact is a new test that simulates a vehicle crashing sideways into a pole, as shown in [Figure 3](#). During the crash, the rigid pole of 254-mm (10-in) in diameter is stationary, and the test vehicle is propelled sideways at 32 km/hr (20 mph) so that its line of forward motion forms an angle of 75 degrees with the vehicle's longitudinal centerline. The FMVSS 214 pole impact sets limits on occupant injury criteria with no structural performance requirements. Since no occupant models were used in this study, the performance was assessed based on the distance between the door-beam and the geometrical centerline of the driver's seat. In general, the maximum intrusion in the pole impact occurs at the front door inner. In the side pole impact, simulation results of the baseline model showed that the rocker was the most influential component controlling the door deformation as measured in this study.

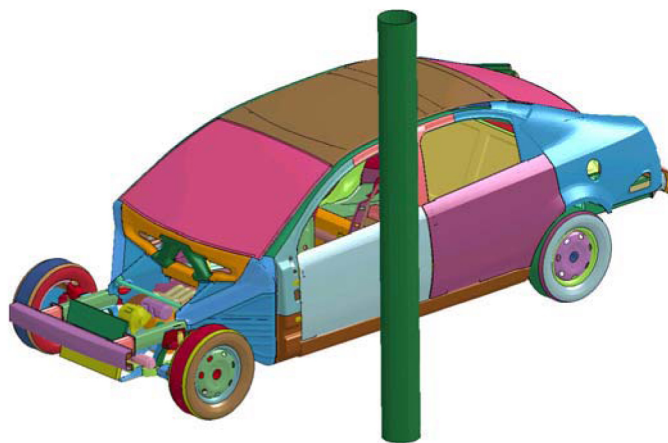


Figure 3. Side pole impact model

IIHS ROOF STRENGTH

The roof crush model is shown in [Figure 4](#), and the load-displacement curve is shown in [Figure 5](#). The load factor is defined as the crush load divided by the unloaded vehicle weight (UVW). The load is applied to the forward edge of a vehicle's roof through a rigid rectangular plate at the size of 762 mm × 1829 mm. Both rockers were fixed in all degrees of freedom in this study. Simulation results of the baseline model indicated that roof rail and B-pillar were key components controlling the roof performance in the IIHS roof strength test condition. [Figure 5](#) shows the baseline model results.

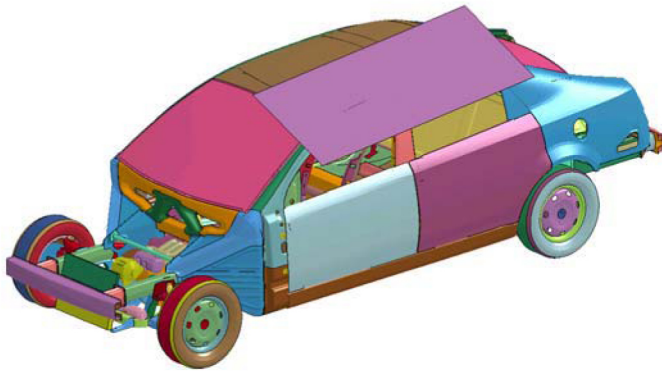


Figure 4. Roof crush model

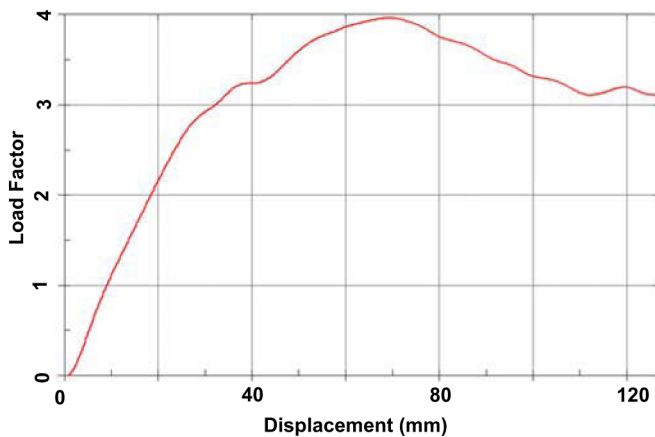


Figure 5. Roof crush load-displacement curve for the baseline model

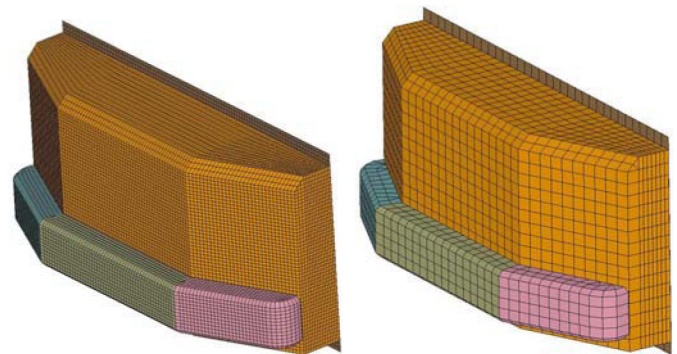
MOVING DEFORMABLE BARRIER (MDB) MODELS

The moving deformable barrier models used in this study were developed by LSTC using 16-mm solid elements in LS-DYNA® to simulate the honeycomb barrier material [8,9,10]. LSTC verified the barrier models with 20 km/hr pole impact test and 30 km/hr flat wall impact test with good correlations.

The original IIHS barrier model has a total number of 130,000 elements. To reduce computational time, particularly for the optimization runs, the element size for solid elements was increased to 50 mm and the total element number decreased to 37,000 as shown in [Figure 6](#). [Figure 7](#) shows the comparison in the performance of the IIHS barrier model between fine and coarse meshes in 30 km/hr flat wall impact test and 20 km/hr pole impact test, respectively. The barrier response is slightly stiffer with the coarse mesh, but still matches the physical test results well.

The geometry and position of IIHS and LINCAP MDBs relative to the test vehicle are compared in [Figure 8](#). The LINCAP MDB weighs 1370 kg and represents the front end of a passenger car, while the IIHS MDB weighs 1500 kg and represents the front end of a SUV or pickup truck. The IIHS barrier is higher off the ground, taller, and contoured.

[Figure 9](#) shows the cross-sectional view of the deformation modes of the baseline vehicle in side impact simulations using the IIHS and LINCAP MDBs. More B-pillar deformation was observed in the IIHS test condition, whereas the LINCAP test condition resulted in more deformation around the rocker at a relatively lower position.



(a) Original fine mesh

(b) Coarse mesh

Figure 6. Meshes for the IIHS MDB