

Rapid Design Solutions for Automotive Bumper Energy Absorbers Using Morphing Technique

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Abbreviations:

OEM – Original Equipment Manufacturer
EA – Energy Absorber
CAE – Computer Aided Engineering
FMVSS – Federal Motor Vehicle Safety Standards
FE – Finite Element
CMVSS – Canadian Motor Vehicle Safety Standards
IIHS – Insurance Institute of Highway Safety

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Abstract

Automotive product development cycles are getting shorter by the day. With increasing competition in the marketplace, the OEMs and suppliers' main challenge is to come up with time-efficient design solutions. Novel products such as thermoplastic bumper energy absorbers face this challenge to a much greater extent. This is due to the fact that in addition to meeting many conflicting performance and cost requirements, it is also necessary to convince the OEMs about the new technology. This calls for a need to come up with a number of alternative design solutions in less time and cost, compared to traditional product suppliers. These design solutions are best achieved in a CAE environment using some of the modern software tools. Such tools are capable of effecting quick changes in the design such as change of shapes. Morphing techniques assist in this crucial stage by letting the design / analysis engineer try out numerous shapes in a very short span of time and to come up with the best shape. This paper explores the use of morphing functionality in HyperMesh™ applied to such thermoplastic bumper energy absorbers. The results obtained show the effectiveness of morphing applied to design of automotive bumper systems.

Introduction

Automotive bumper systems are designed to prevent or reduce physical damage to the front and rear ends of passenger motor vehicles in low-speed collisions. They protect the hood, trunk, grill, fuel, exhaust and cooling system as well as safety related equipment such as parking lights, headlamps and taillights in low speed collisions. By limiting physical damage to expensive components, bumper systems reduce insurance expenses for OEMs. Different countries have different performance standards for bumper systems. Bumper systems on vehicles sold in North America are required to meet 4 km/hr FMVSS (Federal Motor Vehicle Safety Standard) pendulum and barrier impacts [1] and 8 km/hr CMVSS (Canadian Motor Vehicle Safety Standard) pendulum and barrier impact requirements. In addition, most bumper systems are also designed to meet 8 km/hr IIHS (the Insurance Institute for Highway Safety) 30° corner and flat barrier impact. Bumper systems on vehicles sold in Europe and Japan are typically designed to withstand 4 km/hr ECE42 pendulum

impact and 15 km/hr offset Allianz barrier impact. Future front bumper systems sold into European markets will need to meet pedestrian safety requirements in addition to ECE42 and Allianz barrier requirements. In addition, many global vehicle platforms will be sold unchanged in European, Japanese and North American markets. This will require a focus on vehicle structure and styling that is flexible enough to meet all of the global legislative impact requirements.

Many energy absorbing bumper systems have been proposed to meet the challenges faced by the bumper designer. An energy absorbing bumper system made of a foam type resin of polypropylene, polyurethane or the like is one such concept [2]. Another foam type energy absorbing bumper is a semi-rigid resilient fascia spaced forwardly of the bumper structure and the volume defined there between filled with an integral skin urethane foam that is resiliently deformable and integrally bonded to both members [3]. However, a non-foam type injection-molded thermoplastic energy absorber made of PC/PBT [4,5] has been demonstrated as having the highest efficiency of energy absorption and more consistent impact performance over a range of temperatures.

Injection-molded PC/PBT energy absorber offers the bumper designer many design features consisting of both size and shape design variables to customize it for any particular vehicle front-end styling and structural parameters. A series of shape and size optimization studies are performed on the baseline design for a given car model and the optimum design parameters are used in the final design, minimizing cost and maximizing performance. This paper describes an automated shape and size optimization process using Altair HyperMorph 7.0 and Altair HyperStudy 7.0, which further enhances the competitive advantages of the injection-molded thermoplastic EAs.

Process Methodology

Optimization of injection-molded thermoplastic bumper energy absorbing crush boxes under regulatory impact loading condition, FMVSS 581 pendulum test, was carried out. An idealized model representing the bumper system was prepared. The model contained a steel bumper-reinforcing beam mounted on two side members, also known as rails. The thermoplastic energy absorber, designed to be positioned between bumper beam and bumper cover in actual vehicle, was mounted onto the bumper beam at specified places using rigid connections simulating snap-fits. From earlier experiences, it was seen that plastic bumper cover doesn't participate much in the energy absorption process. Hence it was not included in the model. The model was constrained at the end of rails. The energy absorber (EA) was divided into four zones, front, rear, flange and strap areas. The front and strap areas were taken as design areas and flange and rear areas were considered as non-design areas. Fig 1 shows the FE model and design areas of energy absorber.

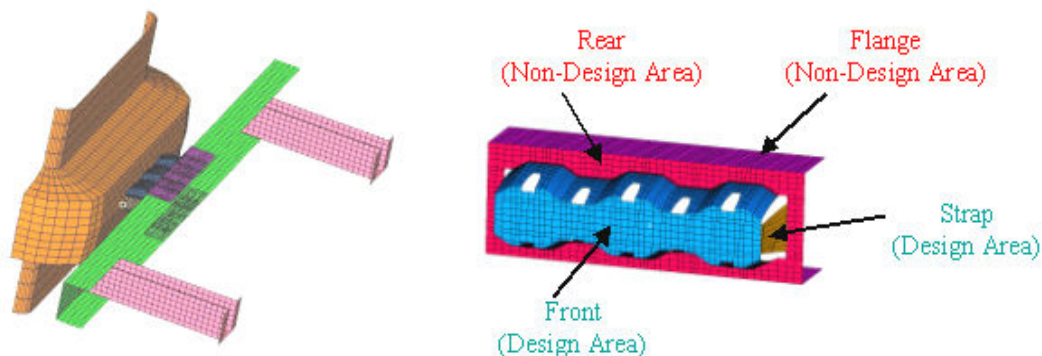


Figure 1 : Finite Element Model and Energy Absorber Design Areas

Eight design variables were defined to parameterize the design space. The design variables consisted of two size variables and six shape variables. The size variables were the thicknesses of EA Front and EA Strap. The shape variables are shown in Fig 2.

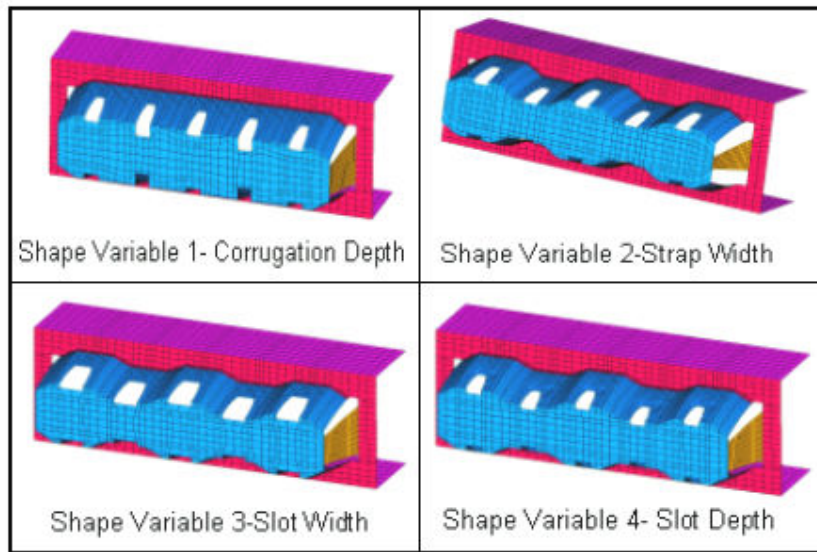


Figure 2: Illustration of Shape variables

The list of variables with their nominal value and ranges are shown in Table 1.

Table 1: Optimization Variables and Ranges

Variable Type	Variable Name	Nominal value	Lower Bound	Upper Bound
Size	Front Thickness	2.25	1.8	3.5
	Strap Thickness	1.8	1.8	3.5
Shape	Corrugation Depth	5	10	0
	Strap Width	17.5	17.5	7.5
	Slot Width	9	4	14
	Slot Depth	19.5	24.5	14.5

Three responses were defined for optimization study, intrusion (x-displacement of pendulum after impact), maximum force on rails and back-of-beam displacements. Minimizing the pendulum intrusion was the objective of the optimization study with constraints placed on the other two responses. Maximum force on rails was constrained to be below 20 kN and maximum back of beam displacement was limited to a maximum value of 5 mm. Table 2 lists the optimization objective and constraints with convergence criteria details.

Table 2 : Objective Function, Constraints and Convergence Criteria

Objective Function	Intrusion	Minimize
Constraint 1	Max Dynamic Force on Rails	< 15 kN
Constraint 2	Max Dynamic Back of Beam Deflection	< 5 mm
Relative Convergence %	3	
Design Variable Convergence %	3	
Max no of Iterations	50	

Sequential Response surface method was used for optimization study. The baseline LS-DYNA deck was prepared using Altair's Hypermesh 7.0 and shape design variables were created using HyperMorph 7.0 [6], an integral part of HyperMesh 7.0. Hyperstudy 7.0 [7] was used to carry out the optimization study. Windows OS was used for HyperWorks environment and Linux OS for LS-DYNA solver.

Results & Discussions

The optimization run converged in 15 iterations satisfying all constraint non-violation and convergence criteria. History of objective function and constraints is shown in Figures 3.

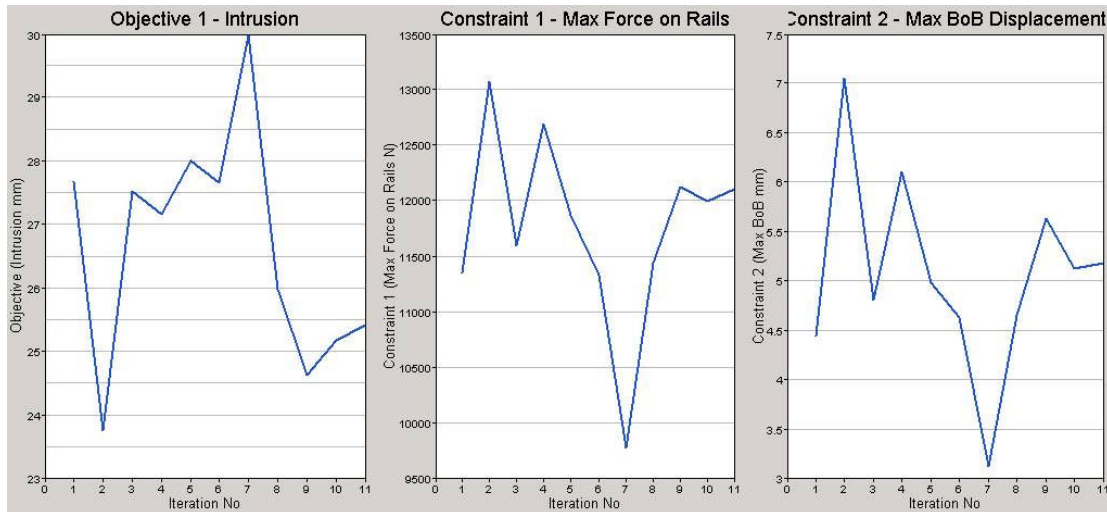


Figure 3: History of Objective function and constraints over iterations

Size and shape variable changes over iterations are shown in Figure 4.

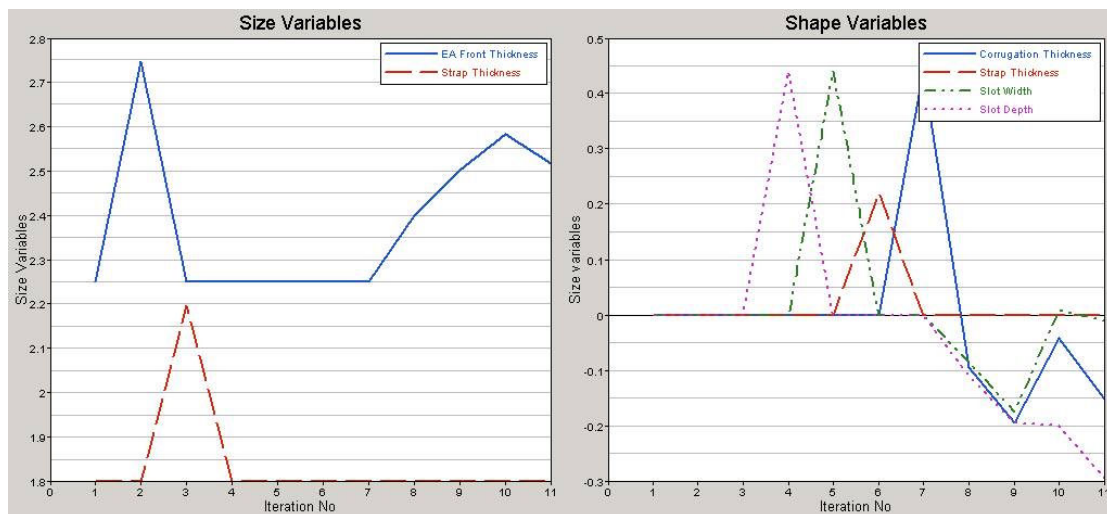


Figure 4: Variations in Design Variables over Iterations

Comparison of initial and final values of design variables with values of constraints and objective Function is listed in Table 2.

Table 3 : Comparison of Initial and Optimized Design

Parameter Type	Parameter	Initial Value	Final Value
Size Variable	EA Front Thickness	2.25	2.52
	Strap Thickness	1.8	1.8
Shape variable	Corrugation Depth	5	5.75
	Strap Width	17.5	17.5
	Slot Width	9	9.05
	Slot Depth	19.5	21
Constraint	Max Rail Force (N)	11344	12097
	Max BoB Displacement (mm)	4.44	5.18
Objective Function	Intrusion (mm)	27.7	25.4

Optimized design improved intrusion performance by almost 10% while optimally utilizing margins on constraints. Optimized geometry involved major change in thickness of EA front, corrugation depth and slot depth while the other parameters were almost unchanged.

Benefits

Number of iterations to arrive at an optimized energy absorber design for a given loading condition without the help of software may take a number of iterations, going up to as high as 15 in some cases. The direction of design change is mainly based on intuition and the analysis engineer's domain expertise. This involves significant investment in time from design and analysis engineer. The automated optimization environment saves this time. It also helps utilize the solver machine hours most effectively. All these benefits reduce the optimization process to a matter of days from couple of weeks.

Challenges

Proper definition of optimization controls is the toughest challenge in the whole process. To make the most efficient use of the tools, optimization should preferably converge in one attempt (set of iterations). The user should take a judicious and informed decision regarding definition and bound specification of the design variables and constraints, convergence criteria and optimization algorithms. Too narrow a design space or too tight convergence criteria may lead to non-convergence even at the highest number of iterations. On the other hand, too liberal convergence criteria would lead to a solution, which may not be the optimum solution. Proper engineering judgment should be employed to strike a balance between the two.

Differentiating between local optima from the global optima is a challenge present in all optimization software. Domain expertise is the key to differentiate and should be used effectively, and in all likelihood the appropriate choice of the optimization algorithm will decide whether the solution is globally optimum.

Linking of pre/post environment (such as HyperWorks) to solver environment (such as LS-DYNA) is a different type of challenge, which is easy to handle with proper system administration knowledge.

Future Plans

Successful implementation of size and shape optimization under a single impact loading condition is over. Optimization under a series of impact loading conditions is on the anvil. This will help in further productivity enhancement since the same energy absorber is required to withstand a number of impact loads and still perform satisfactorily. Also, efforts are being directed towards automatic deletion of huge-sized restart files like d3dump to minimize the disk space.

Conclusions

Engineering Thermoplastic based PC/PBT energy absorbers have tunable design features to satisfy varying car geometries, stiffness requirements and a range of performance criteria. Numerous size and shape design features available to designers can be suitably controlled to arrive at an optimum design to satisfy various conflicting requirements such as performance and cost. High-end automated Optimization tools such as HyperMorph, HyperOpt and HyperStudy help in rapid optimization of energy absorbers involving numerous design variables and constraints to help suppliers to stay competitive with respect to timeline.

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