A METAL PLASTIC HYBRID (MPH) RAIL EXTENSION DESIGN SOLUTION FOR AUTOMOTIVE BUMPERS TO ADDRESS THE INSURANCE INSTITUTE FOR HIGHWAY SAFETY (IIHS) SMALL OVERLAP RIGID BARRIER IMPACT TEST (SORB).

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Abstract

The advent of Insurance Institute for Highway Safety (IIHS) small overlap rigid barrier (SORB) protocol has led to the development of vehicles with an extended and/or standalone rail extension to help address the SORB test. In this study, a generic LS-DYNA® model vehicle modified with metal plastic hybrid (MPH) SORB rail extension was compared to a baseline metal (steel) rail extension. A new method of combining the mechanical performance of metal with the energy absorbing ability of polymer in a rail extension has been devised using an MPH approach. A simple but effective MPH design was envisaged for the rail extension and evaluated for front bumper impact requirements for energy absorbing. It was observed that the passenger compartment of the vehicle under investigation incurred minimal damages in the event of a small overlap impact and that the MPH rail extension delivered similar performance as the metal rail extension in the vehicle structure. When comparing the MPH solution to the full metal rail extension, the MPH solution was lighter in weight and reduced system cost for automotive bumpers.

Introduction

The IIHS has been involved for long in making vehicles safer for occupants. The industry regulators have come up with many standards and recommendations to address the effect of a car crash on the occupants. Among the many tests available for structural evaluation of a vehicle under an impact load, the assessment of the SORB regulation has recently gained significant traction. The assessment was done by subjecting the physical vehicle to a physical test as per IIHS SORB regulation [1]. This was a costly test and before subjecting an actual vehicle to such a test, the effectiveness of the SORB modification in general and the outcome of the tests are assessed using a transient dynamic simulation software’s like LS-DYNA® or any other commercially available software’s. Automotive companies spend a great deal of money, engineering effort and time to modify existing vehicles to meet new regulation like SORB test or design newer vehicles by taking into account the new regulation. This study builds on the report and Finite element analysis (FEA) model generated by The U.S department of transportation National Highway traffic and safety administration (NHTSA) and made available as DOT HS 812 237 to the general public.

In 2011, NHTSA funded a study to design a future midsize lightweight vehicle (LWV) [2]. In that study a model 2011 Honda Accord was selected as the baseline vehicle (LMV 1.0). Honda provided comments to NHTSA on the findings. Since the release of the IIHS small overlap
frontal crashworthiness evaluation crash test protocol. The IIHS has evaluated numerous midsized and small cars, with few vehicles earning the top rating of good, particularly due to the structural performance rating [3]. Most of the vehicles on the road in 2012 could not meet the targets for a ‘good’ rating in this test and all vehicle manufacturers started incorporating countermeasures to improve SORB performance [4]. In 2013, NHTSA awarded a subsequent contract to modify the initial LWV design to update the design to address Honda’s comments (LWV1.1) and update the design to correlate to the IIHS Small Overlap (SOL) crash test results (LWV1.2). [2]. The outcome of the SOL test for LMV 1.2 finite element (FE) model was observed to be very good and hence is the baseline finite element model for this study.

Figure 1 Generic vehicle structure with rail extension.

A generic vehicle structure is shown in Figure-1. A rail extension is a component which connects the vehicle bumper to main rail and side rail of the vehicle chassis. Generally there are two rail extensions attached on each side of the chassis. One of the rail extension is called the main or primary rail extension and the second rail extension is called the SORB rail extension, as the primary reason for having this second rail extension is for the purpose of mitigating IIHS SORB protocol.

Metal rail extension present in the LMV1.2 vehicle is made of conventional automotive grade steel and is less efficient for the application by virtue of its weight. In the current economic and automotive scenario, the significance of fuel efficiency and vehicle light weighting cannot be underestimated. This paper discusses an innovative way to reduce our dependence on conventional material and at the same time meet the requirements of SORB protocol and do so more efficiently. The use of PMH in a passenger's car B-pillar was demonstrated in the past by SABIC [5]. This study, based on simulation results, showed that a potential weight saving of up to 25 % was possible at similar performance as a high strength steel reinforcement [6]. A similar MPH approach was taken in this study, the LMV1.2 FE model was modified to accommodate a metal plastic hybrid (MPH) rail extension (RE). The SORB simulation was repeated for the LMV 1.2 vehicle FE model fitted with the MPH rail extension. The observations, finding and conclusions are recorded in the subsequent sections of this paper.

IIHS Small-overlap Frontal Barrier Test

The IIHS SOL test was designed to reproduce what happens when the front corner of a vehicle hits another vehicle or an object like a tree or utility pole [2]. Many crash tests were performed before arriving at one configuration of a barrier design. Despite differences in test configurations, these tests had many similar characteristics and matched trends seen in real-world crashes [7]. The small overlap barrier crash tests are conducted at 64.4 ± 1 km/h (40
± 0.6 mi/h) and 25 ± 1% overlap. The test vehicle was aligned with the rigid barrier such that the right edge of the barrier face was offset to the left of the vehicle centerline by 25 ± 1% of the vehicle width [1] (Figure 2).

![Vehicle impact setup for Small Overlap Barrier Test.]

Material and material model introduction

This section of the study introduces the NORYL GTX™ resin, which is an alloy of Polyphenylene Ether (PPE) + Polyamide (PA). This injection moldable grade exhibits high heat resistance, excellent chemical resistance and high melt flow for optimized process ability. NORYL™ GTX resin is impact modified and designed for automotive exterior thin wall, large parts such as body panels. [8]

The material model used for evaluating the plastic behavior in the MPH rail extension is MAT187 or SAMP-1. This is an accurate card which can capture the behavior of plastics. The model applies a yield criteria based on an isotropic C1 smooth yield surface, and the plastic flow rule is expressed using a non-associated potential function. The model takes into account the pressure dependency by taking a yield function, which incorporates pressure state. The softening and volumetric change of the plastic is accounted for by incorporating a parameter which is a function of plastic Poisson’s ratio in the plastic potential function. In MAT-187, the yield surface is internally modified according to the type of stress-strain curves given as input.

1. Tensile test data is mandatory and if only this curve is given as input, then Von-Mises yield criterion is applied.
2. Along with tension, either compression or shear data is provided when the Drucker-Prager yield criterion is applied. Upon inputting all the three modes of stress, the SAMP-1 yield criteria is implemented.

In order to predict the failure and damage, the GISSMO (Generalized Incremental Stress-State Dependent Material model) model is used. GISSMO model, needs several parameters to capture damage. Since plastic volume dilates under tension, true stress needs to be computed from actual force and transverse area, Poisson’s ratio was used to compute the transverse area, by assuming Poisson’s ratio to be transversely isotropic with respect to specimen axis. Shear values are also scaled to obtain a convex yield surface. Plastic strain rate was determined to be some factor of nominal strain rate, and is used to assign tensile values in a table [9]. The MAT 187 model and GISSMO failure model is used in the evaluation for improved accuracy.
Metal Plastic (GTX) Hybrid Rail extension.

This section of the study explains the attempt to develop a metal plastic hybrid (MPH) SORB rail extension unit using a combination of Internal rail extension made of NORYL GTX™ material (introduced in the earlier section) and an external metal reinforcement made of steel. The image of the same has been shown below in Figure-3

![Figure 3 Metal plastic Hybrid (MPH) Rail extension unit front (left) and rear isometric (right) view is shown.](image)

The MPH rail extension acts a medium to combine the benefits of polymer in crushing and the ability of metal to tensile load. The combination was used to effectively achieve similar performance of as that of the full metal rail extension and at the same time, to do so more efficiently. Two major processes are involved in the making the MPH rail extension, which are:

- Sheet metal forming
- Injection molding

The MPH rail extension has two major components (shown in Figure-4) which are combined to form a single unit. They are as follows:

- A NORYL™ GTX resin rail extension unit.
- A metallic reinforcement made of steel.

![Figure 4 Metal reinforcement (left) and GTX rail extension (right).](image)

The MPH rail extension solution does not call for costly changes to the existing vehicle chassis or sub-assemblies or components. The solution uniquely uses the same packaging space available in the current design to offer a more efficient delivery of similar performance.
An FE model of the MPH rail extension that goes into the vehicle as a sub-assembly is shown in Figure 5.

![Figure 5 FE model of metal plastic hybrid (MPH) rail extension unit.](image)

The sub assembly level setup of the LMV1.2 vehicle FE model fitted with metal SORB rail extension and LMV1.2 vehicle FE model fitted with MPH SORB rail extension solution is shown below in Figure-6.

![Figure 6 LMV 1.2 vehicle with metal SORB rail extension (left) LMV 1.2 vehicle with metal plastic (GTX) hybrid SORB rail extension (right).](image)

In the case of the MPH SORB rail extension, the same setup can be assembled and welded on to both sides of the chassis. The added benefits of using the MPH RE are as follows:

- The entire setup can be e-coated, this is enabled by the NORYL™ GTX resin.
- NORYL™ GTX resin can withstand up to 200°C, without losing its properties.
- The MPH rail extension helps in part integration and simplification.
- The NORYL™ GTX resin rail extension can easily be separated from the MPH rail extension assembly by the method physical separation for the purpose of recycling.
- A single part can be used on both the left side and right side of the vehicle. This helps in reducing part count and spares requirement.

A comparison between the full metal and MPH RE is given in Table-1. It can be seen that the part count has been reduced from 4 to 3 and the weight has been reduced by about 31.14
percentage. The overall cost of the RE unit is also anticipated to be reduced by 10%, which when taken as cumulative over many vehicle and number of year of production of the vehicle, can result in cost competitiveness for the manufacturer.

Table 1: Comparison of metal and MPH SORB rail extension.

<table>
<thead>
<tr>
<th>SI No.</th>
<th>Type of Rail extension/ features</th>
<th>Metal Rail extension</th>
<th>Metal plastic rail extension.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of parts</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Materials</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Steel DP 500-800</td>
<td></td>
<td>Steel DP 500-800 (reinforcement), NORYL™ GTX resin (Rail extension)</td>
</tr>
<tr>
<td>4</td>
<td>% weight saving</td>
<td>-</td>
<td>31.14</td>
</tr>
</tbody>
</table>

Results and Discussion

This section aims to evaluate the effectiveness of the MPH solution. The results obtained for the FE model of LMV 1.2 vehicle was taken as the bench mark. To make that evaluation, the study has taken into account three main aspects (1) the acceleration due to gravity (g) values (longitudinal and lateral) at the center of gravity, (2) the change in velocity of the vehicle (in the longitudinal and lateral direction and finally (3) the crush pattern of the of the vehicle and the LMV 1.2 model fitted with MPH rail extension.

First let us take a look at the longitudinal (X-direction) and lateral (Y-direction) acceleration values as shown in Figure-7 and Figure-8 respectively.

![X-Acceleration](image)

Figure 7 Comparison of longitudinal acceleration for the LMV 1.2 simulation model and LMV 1.2 simulation model fitted with MPH rail extension.
Figure-7 demonstrates that the longitudinal (g) values obtained for LMV 1.2 vehicle fitted with MPH RE shows lower (g) values for the same duration and magnitude of loading.

Figure 8 Comparison of lateral acceleration for the LMV 1.2 simulation model and LMV 1.2 simulation model fitted with MPH rail extension.

It can be observed from Figure-8 that the lateral acceleration values obtained for the LMV1.2 vehicle fitted MPH rail extension more or less fall within the same range of g values as obtained for LMV 1.2 and some area it is considerably lesser. Overall, in comparison to the LMV1.2, the LMV1.2 MPH model is observed to experience less (g) values for the same displacement, duration and magnitude of loading.

Secondly, if we look at the change in velocity at the center of gravity (Cog) location as shown in Figure-9, it can be seen from the results that the LMV 1.2 and LMV1.2 MPH velocity values almost match with each other.

Figure 9 Comparison of Change in velocity (X and Y direction) from the simulation of FE model of LMV 1.2 and LMV 1.2 fitted with MPH rail extension, at the center of gravity.
This close match can be considered as a confirmation that the new simulation studies performed namely the LMV 1.2 and LMV 1.2 MPH are in agreement. However, the way results similar to the LMV 1.2 are obtained with an MPH rail extension which was 31% lighter than the existing all steel rail extension is the novelty.

Finally, for visual inspection, the crush pattern observed for the LMV 1.2 vehicle fitted with MPH rail extension is shown in Figure-10.

![Figure 10 post-crash test simulation deformation results for LMV 1.2 fitted with MPH rail extension in the IIHS small-overlap test.](image)

There is very little damage observed to the occupant compartment. This concludes the study and it can be observed that the deformation patterns post-test for the LMV1.2 and the LMV1.2 finite element model fitted with an MPH rail extension were in agreement with each other. Occupant safety and overall crashworthiness target are observed to have been met, since the acceleration pulses and change in velocity of the two models in comparison in the same direction are similar or lesser in magnitude for the LMV 1.2 model fitted with MPH RE.

**Summary**

The work in this paper has explored an alternative to the standalone metal SORB impactors, by employing a metal plastic hybrid solution approach. The MPH solution combines the benefits of the metal and specialty polymer NORYL™ GTX™ resin in creating a light weight and efficient design.

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