Terocore® Structural Inserts Help Achieve New Roof Strength Targets

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Introduction

Updates to regulation and ratings result in reviewing existing vehicle platforms performance, and making updates to the structure over the production life of the vehicle. In the case of the updated IIHS roof strength ratings, some automobile manufacturers decide to improve the roof strength of the existing vehicle to achieve higher performance. The purpose of this paper to show how structural inserts were designed and integrated into an existing production process. This will be accomplished by reviewing the background of the test, TEROCORE® structural inserts, the design, and implementation process, concluding with the validation of the vehicle performance.

Background

Roof strength in passenger vehicles has been subject to increased focus in the past 5 years, as the National Highway Traffic Safety Administration (NHTSA) continued to consider updating the minimum standards. The Insurance Institute for Highway Safety (IIHS) led the way to higher performance testing by incorporating roof crush testing into the safety pick rating criteria. Both IIHS and NHTSA published new testing standards in 2009.

The IIHS rates vehicles crashworthiness through testing performance in the following areas: Front impact, side impact, rollover and restraints. Vehicles with a good rating in all four tests, and electronic stability control, earn a “Top Safety Pick” rating. These ratings are for consumer information, and are not a requirement.

Testing requirements set forth by NHTSA, in the form of “Federal Motor Vehicle Safety Standards and Regulations”(FMVSS) are regulations written in terms of minimum safety performance requirements for motor vehicles. Vehicles sold must conform and certify compliance. FMVSS 216 is the standard the currently applies to the vehicle here. FMVSS 216a - Upgraded standard, is scheduled to be phased in starting September 2012 and all vehicles should be compliant by September 2015. Unlike the IIHS rating system, which ranks levels of performance, this standard is a mandatory requirement. The requirement includes: head form location and loading restrictions and a load requirement of 3.0 times the unloaded vehicle weight (UVW) for vehicles under 6,000 lbs with testing both driver and passenger side.

The purpose of roof crush testing is to protect occupants in passenger vehicle roll over events. The IIHS and NHTSA both fundamentally perform the same test, although the specifics of the tests vary slightly. The roof crush test is a quasi-static test involving a platen positioned at an angle relative to the vehicle, loading the front corner of the cabin (Figure 1). The force required to push the platen 5 inches is measured, and used to evaluate the vehicle performance. The force exerted, divided by the UVW gives you how many times the vehicle weight the structure can support.

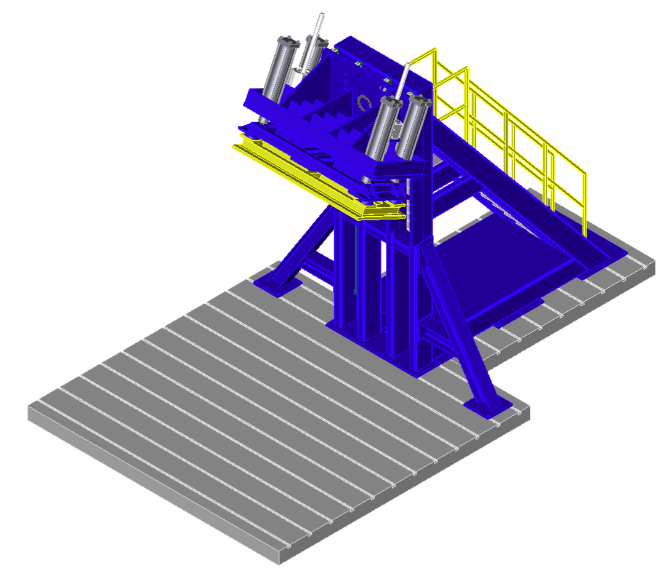

Figure 1: MGA Roof Crush Test System [3]

Structural Inserts

TEROCORE structural inserts can be a mass and cost efficient solution to improve structural performance [4]. To understand how they benefited this project, we must first understand what they are, and how they work.

TEROCORE is the trade name used to identify preformed structural products at Henkel. There are two main groups within the TEROCORE category, expanding structural foam and structural patches. TEROCORE 1811™ is one grade of Henkel's expanding structural foams used in structural inserts. It is an injection molded material, usually used in conjunction with a nylon, aluminum or steel carrier. It is characterized as having superior adhesion, compression, high temperature resistance, and corrosion resistance. The material has a median volumetric expansion of 120% which is obtained by using a physical blowing agent. This imparts a uniform closed cell structure to the foam. The patented inclusion of glass micro-spheres and fibers result in a light weight material while maintaining high compressive strength.

TEROCORE structural inserts are intended to be enclosed within a defined structure. The parts are designed with an offset to the structure, accommodating build variation and tolerance. When the vehicle goes through the e-coat oven, the TEROCORE structural foam expands, filling the gap, and bonding to the surrounding structure. When the parts are bonded together, their Moment Of Inertia (MOI) are additive. So the cumulative benefit is greater than that of the two parts working independently.

The design application for TEROCORE structural inserts includes improved crashworthiness, NVH and durability.

Product Development - Phase I

The Body Structures group at the OEM used CAE simulations to verify the current vehicle performance and to determine the optimal solution to achieve the target performance.

To kick off the project, a baseline roof strength analysis was run based on production content to determine the gap to target for the IIHS performance. The baseline performance of the car was analytically determined to be at 65% of the IIHS target performance.

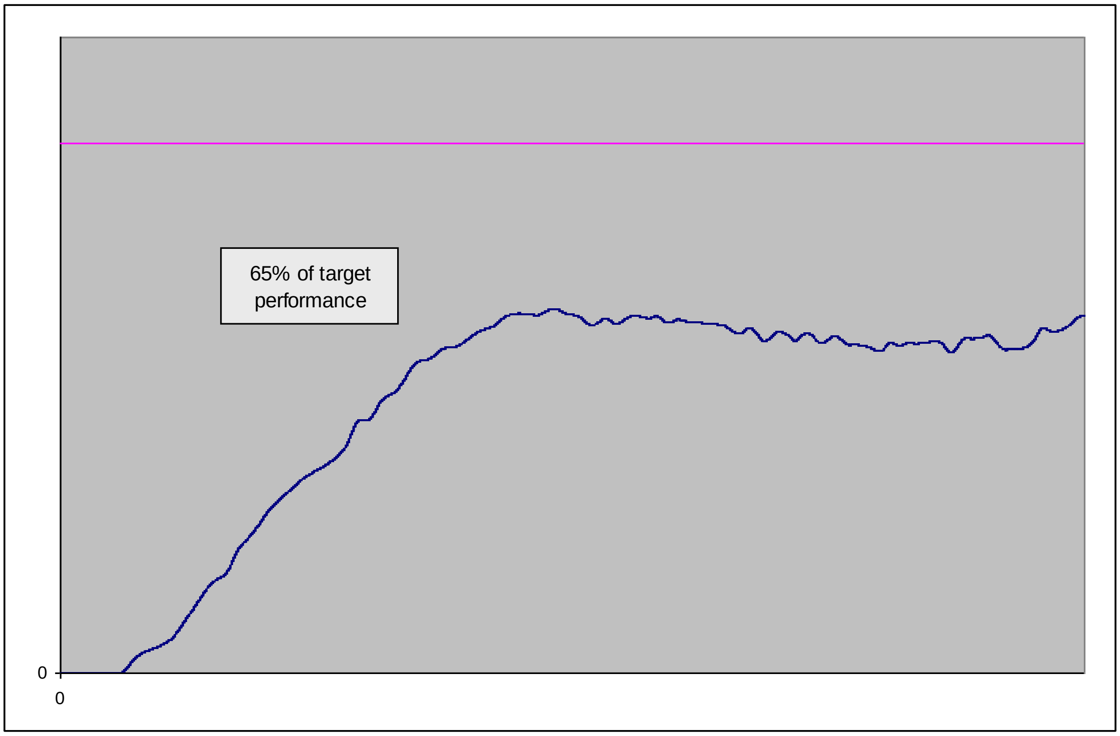

Figure 2: Force vs. Displacement Curve for base performance

The deformed shapes from the baseline analysis were studied to determine design direction. Three areas were identified for potential improvements: the header to side frame joint, the roof rail, and the center pillar.

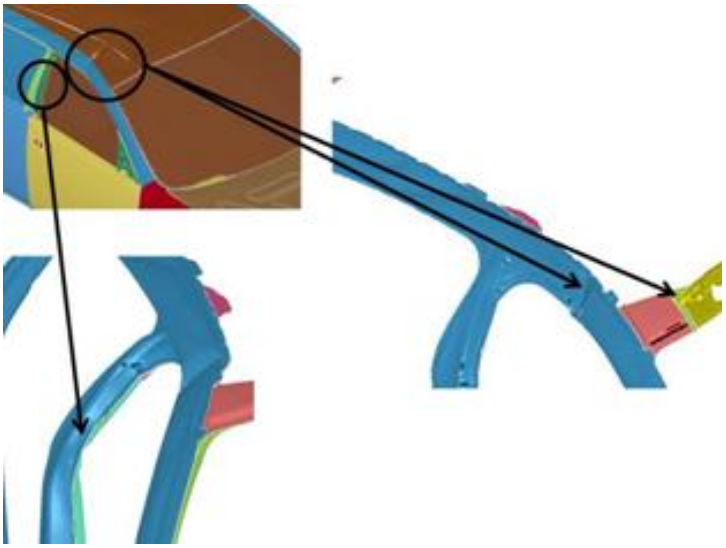

Figure 3: Potential improvements

For the header joint, structural adhesive was added in the rear flange to improve the joint connectivity for roof strength. For the center pillar and the roof rail, more extensive changes were needed to improve the buckling modes. A study was conducted to determine the most efficient strategy to improve these two areas. Based on program status, it was determined that a structural insert strategy would be the most efficient means for improvement. To test this conclusion, an analytical model was constructed where both the critical areas of the roof rail and center pillar were “filled” with a mesh representing a composite material and this mesh was analytically bonded to the surrounding steel.

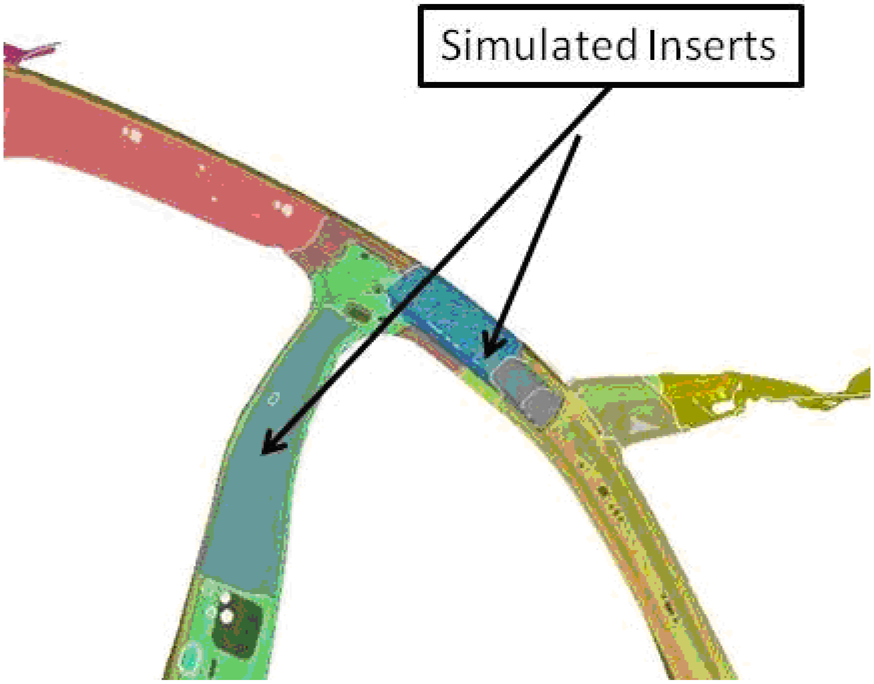

Figure 4: Design Location

The results for both force capacity performance and resulting deformed shape satisfied the anticipated improvements.

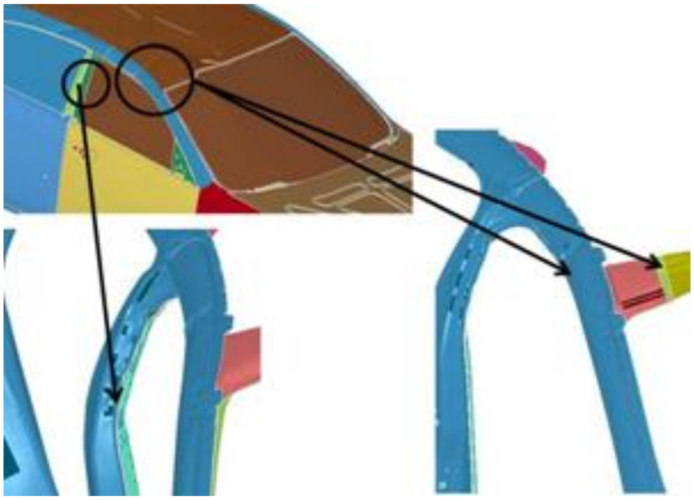

Figure 5: Shape of Design location with filled design

Based on the improvements with the conceptual inserts, design direction-was set to pursue a structural insert strategy for roof strength improvement.

Product Development - Phase II

The product development process included simulation performed at the OEM in addition to design and development of structural inserts by Henkel.

With the locations for the structural inserts known, Henkel engineers began work on developing a manufacturable design solution. The process included concept development using the FEA model, CAD, optimization and robustness studies. Glass fiber reinforced nylon injection molded inserts with TEROCORE over-molding were selected for the design construction based on the ability to create a lightweight solution for high volume production.

The first step in the development process was to evaluate the package space. The upfront analysis performed by the OEM gave the location, but packaging for pins, and bonding surfaces were not considered. Bonding to class A surfaces was avoided to prevent read-through issues. This drove the initial orientation of the roof rail inserts. The b-pillar inner reinforcement had many holes for attachment features. This package space needed to be protected, which also affects the orientation of the insert design.

The second steps in the concept development included assessing the type of loading in the structure and primary function of each insert. The b-pillar insert supports the b-pillar in bending and prevents buckling. The insert needed to create a specific stiffness in the b-pillar. A higher or lower stiffness would result in a lower force response. The combination of package and performance led to a hat section insert, supporting the inner and outer pillar reinforcements.

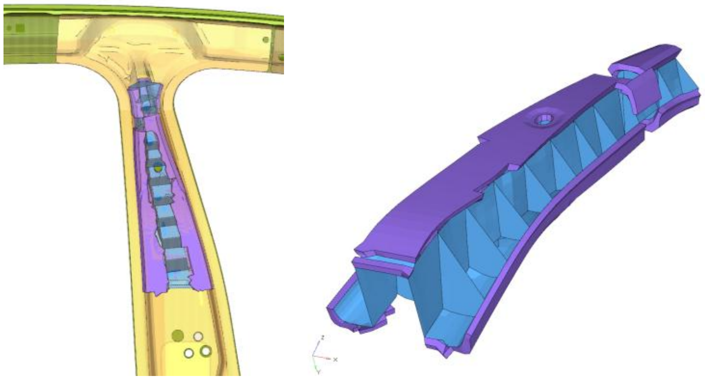

Figure 6: B-Pillar insert concept - supporting inner and outer reinforcements

The roof rail insert was more complicated. Due to the construction of the steel in the roof rail and b-pillar joint, the insert needed to support bending and torsion loads. The area also needed to absorb energy during the event. If the insert was overly rigid, the load path would be driven outside of the target areas, and ultimately result in a lower force response.

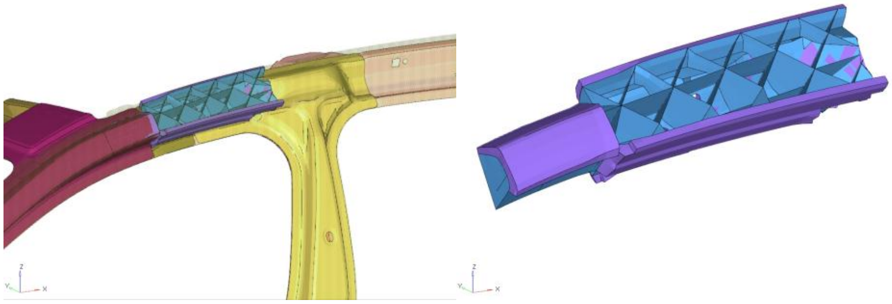

Figure 7: Roof rail insert concept

Multiple design concepts were evaluated to find a pair of inserts achieving target. From the initial concepts, two roof rail inserts and one b-pillar insert were chosen for cost and manufacturing evaluation. The preferred parts were sent to the CAD group.

Building the part in CAD invariably leads to changes in the design. This is attributed to variation between the FEA model and the CAD, mid-surface meshing compared to the 3D steel, and tolerance when offsetting steel faces. CAD also incorporates more information regarding pins, bolts, and retaining features. Additional feasibility reviews were held to ensure the part was manufacturable. A more in depth study of the manufacturing process was also considered to ensure the design solution could be implemented.

The FEA model was updated with the inserts from CAD. The design differences resulted in a drop below target performance. This was due to a step in the roof rail insert, where it transitioned under a steel reinforcement in the body. Due to the bending and torsion in the part, the load needed to be better transitioned between the two sections of the insert.

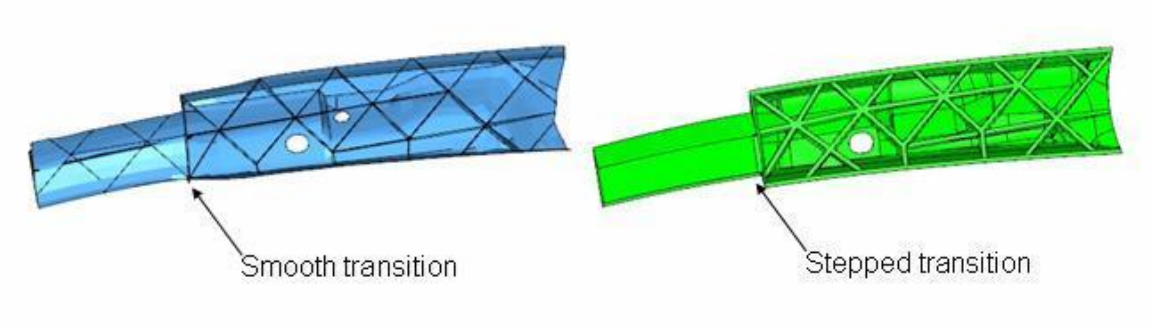

Figure 8: FEA mesh translated to CAD design

The design was modified to achieve an improved load distribution between the two sections of the roof rail insert. This was accomplished through telescoping the forward section of the part into the rear. This design iteration also incorporated additional changes based on manufacturing and weight reduction.

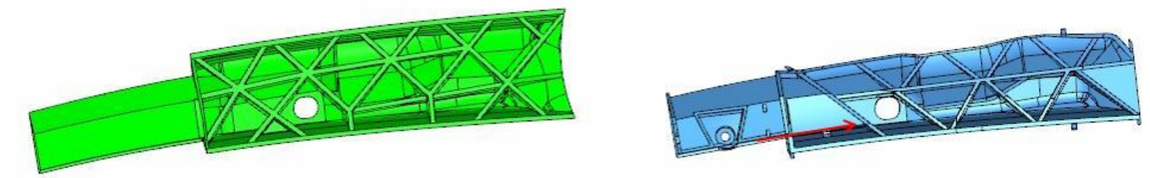

Figure 9: Improved load transfer through part

The b-pillar insert also went through additional manufacturing and weight optimization studies. Evaluation of the plastic strain and deformation of the part led to optimization of the ribs and flanges.

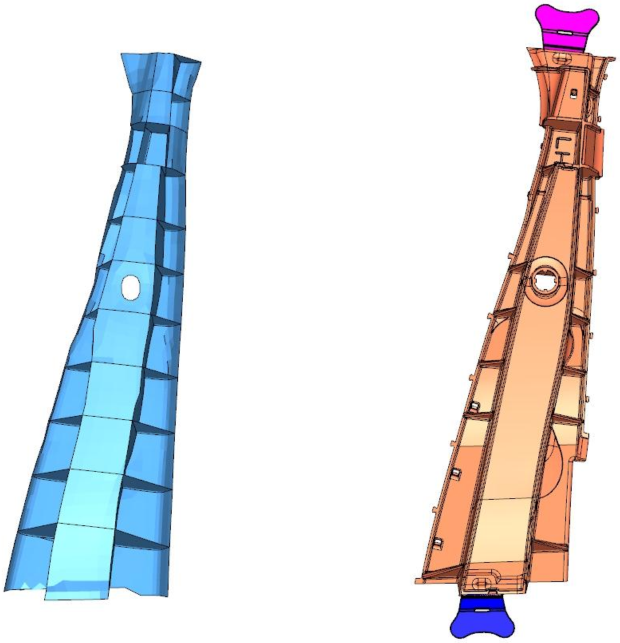

Figure 10: Initial FEA concept and Final CAD part

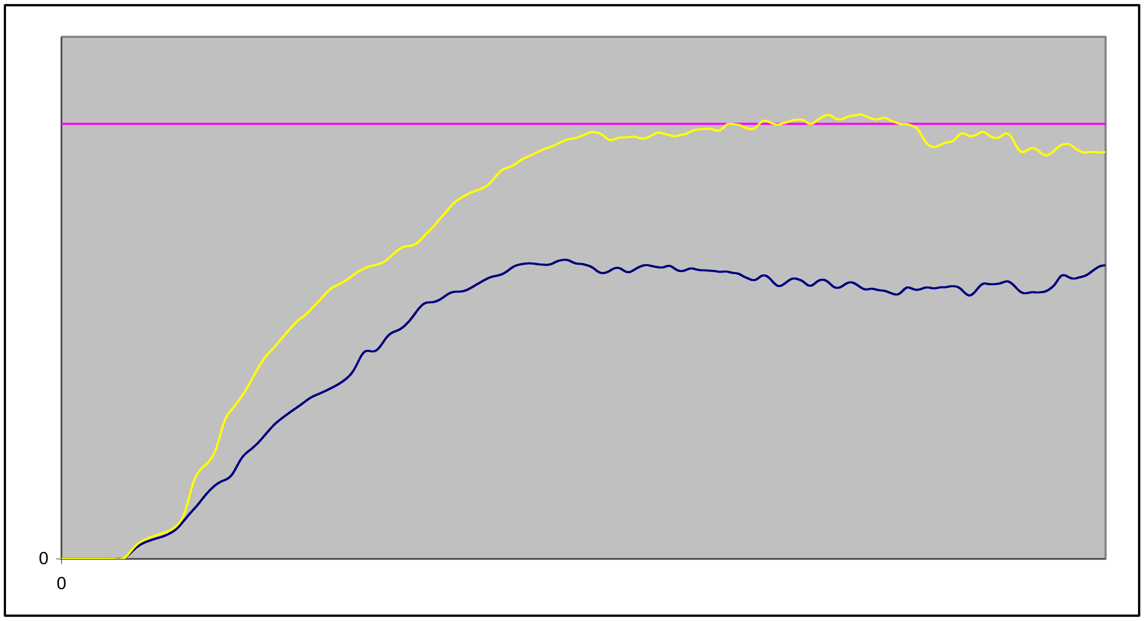

Figure 11: Final FEA model vs. baseline

Based on the final design iteration, a robustness study was performed to ensure the part would perform at the required level. The study evaluated performance based on geometry, material and bonding variation. The material variation incorporated evaluation of the weldlines based on mold-flow simulation.

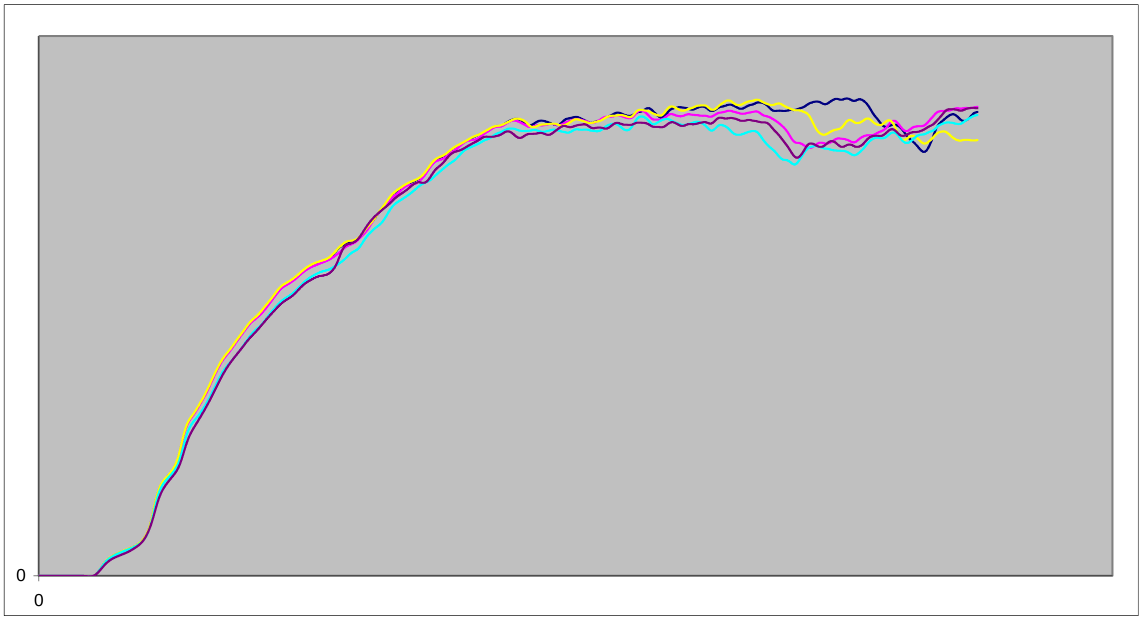

Figure 12: Robustness studies - Force vs. Displacement Curves

The studies confirmed the design stability, and the final CAD was released for hard tooling.

Implementation

The implementation plan of the structural solution was run concurrently with the product development. The plan included process planning, assembly, prototypes, and PPAP. Process planning and assembly was initiated at the onset of the project. This tied in with the product development, to ensure that the parts could be incorporated into the current assembly process.

Three prototype builds planned before the Inserts were implemented. Aluminum tools were used for the prototype structural inserts. This allowed for a shorter lead time to production intent parts, and to verify the processing parameters of the inserts. The prototype vehicle builds with the structural inserts were followed through body, paint and trim shops. Feedback received during the builds was used to modify the Inserts and improve the process. For example, a nylon rib was found to interfere with a trim component. This was easily corrected in the hard tools. CAE was re-run with the change to confirm that performance did not degrade. Elpo oven temperatures were measured near the location of the Inserts to give confidence in the curing and expansion of TEROCORE. Paint cure and top-coat adhesion was also checked in cooperation with the respective suppliers. Oven temperatures were raised by 5F to address a borderline paint cure condition.

The OEM's assembly plant was able to implement both the Inserts with minimal fixture changes and robot reprogramming. This avoided the need for expensive new fixtures and a tear up of the body shop. Error proofing was added to give confidence in high volume production. Ergonomic issues concerning insertion force on a push pin were also addressed in the hard tool. Existing storage racks had to be modified to accept the assemblies with Inserts on them. Shipping and dunnage was designed by Henkel in cooperation with the OEM to meet the requirements at the body shop stations as well as to withstand the journey from Richmond, MO to the OEM assembly plant.

Before PPAP, the hard tools were run at rate and the injection molding process was stabilized and optimized. Quality assurance documents and procedures were also developed by Henkel in cooperation with the OEM's Supplier Quality group.

Validation

The validation of the inserts and the vehicle took part over several phases. The testing included material verification, component level testing, OEM internal testing and finally the IIHS test associated with the performance ratings.

The component level testing was performed at Henkel's Madison Heights Tech Center. This included material verification of injection molded plaques, and 3 point bend testing of the structural insert to verify the part strength.

The OEM tested the vehicle to verify the simulation results. The vehicle was setup according to the IIHS specifications on the driver's side. The force response of the vehicle met the target load. Simulation results were consistent with the test. Overall, there was more than 35% improvement in roof strength.

Figure 13: FEA simulation (5 inches)

Figure 14: Post-test (10 inches)

Conclusions

Using structural inserts, the OEM was able to improve the roof crush performance of the vehicle without significant changes to the manufacturing process, and no changes to the existing vehicle tooling. FEA simulation was used to evaluate the roof crush performance of the vehicle and develop the inserts to achieve the new performance target. The implementation of the inserts was supported by Henkel to ensure a smooth and successful transition. The project culminated with testing of the updated vehicle and the FEA results were validated with testing. The vehicle reached target in both the internal OEM testing, and at IIHS.

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Reference

1. http://www.iihs.org/
2. http://www.iihs.org/ratings/roof/information.html
3. http://www.iihs.org/ratings/protocols/pdf/test_protocol_roof.pdf
4. Gupta, S., 2001, “Evaluating Structural Foam as an Alternative to Steel in a Front Offset CAE Analysis,” ESV Paper 100.
5. http://www.autoblog.com/2009/03/24/iihs-debuts-new-roof-strength-crash-test-small-suvs-rated-first/
6. http://www.fueleconomy.gov/feg/driveHabits.shtml
7. http://www.nhtsa.gov/
8. MGA Research Presents: FMVSS 216A and IIHS Roof Crush Workshop, October 21, 2000
9. http://www.nhtsa.gov/cars/rules/import/fmvss/index.html
10. Wycech, J., Butler, M., 2003, "Influence of Structural Foam Properties on the performance of Automotive Body Reinforcements," SAE Paper 2003-01-326
11. Welters, Tim, “Lighter, Stiffer, Stronger“ Kunststoffe International, Volume 99, November 2009
12. http://www.nhtsa.gov/
13. LS-Dyna keyword User's Manual,
14. Butler, M., Wycech, J., Parfitt, J., and Tan, E., 2002, "Using TEROCORE Structural Foam to Improve Bumper Beam Design," SAE Paper 2002-01-2018
15. Rigid Plastic Foams, T H Ferrigno, 1963
16. Fickes, J., Schroeder, S., Nadkarni, G., Agarwal, R., "AHSS Weld Bond - Energy Management: Drop Tower Investigations" Great Designs in Steel Seminar, 2008
17. Hornug, M., Hajj, M., "Structural Bonding for Lightweight Construction" Material Science Forum Vols. 618-619 2009 pp 49-56