Automotive Hood Inner Panel Optimization with Tosca Structure.bead

Alfonso Hickman, Miguel Caudillo and Rabin Bhojan

Ford Motor Company de Mexico S.A. de C.V, Body and Closures CAE Division

Abstract*: Undesired deformation of vehicle front hoods during the E-coat process panel is an added concern that necessitates determining the optimal structural performance of the hood assembly system during the manufacturing process, in addition to those during its service life, all at a minimum cost and weight. Key quality factors such as functional structural stiffness, and maintaining its geometry and appearance during the stamping, painting, final assembly, distribution and customer usage stages during the product life cycle are the main focus point of this study.*

Typically, stiffness, weight and cost are counter intuitive objectives. In order to achieve a higher engineering efficiency, which is one of the main goals, an optimum trade off of the afore-mentioned attributes are required at the vehicle, system, subsystem and part levels.

In order to increase the stiffness without adding weight, Optimization using Tosca significantly helps engineers to know how to distribute and orient the most efficient bead patterns along the sheet metal structure. Using an automatic Tosca Structure.bead set up the optimal bead layout was achieved after only three finite element analysis iterations. Manufacturing and design requirements were directly and indirectly applied to reach a faster turnaround, from analysis to a feasible design.

Keywords*:* Design Optimization, Bending, Topography, E-Coat process, Stiffness, Structure under Gravity, Non-Linear Analysis.

1. Introduction

Modern vehicles' designs intend to satisfy the comfort, safety, usage performance, fuel efficiency and other customer requirements. Offering the latest technology, with light weight designs, at a low cost within a drastically reduced product development time for high volume products are the essence of today's manufacturers' strategies.

The hood assembly system is one of the exterior systems in the front of the vehicle. Depending on the manufacturer and vehicle, the hood assembly is typically steel or aluminum sheet metal, while some include applications of composite materials.

A typical hood assembly subsystem comprises of a hood inner panel, an outer panel with a hem that connect the inner and outer panels on the edges, a number of reinforcements depending on architecture, hinge mechanisms, a striker (for latching), adhesives, insulators and others.

The main attachment methods to assemble the parts into the system are the use of spot-welds, rivets for aluminum applications, and structural adhesives. An example of the hood system is presented in Figure 1.

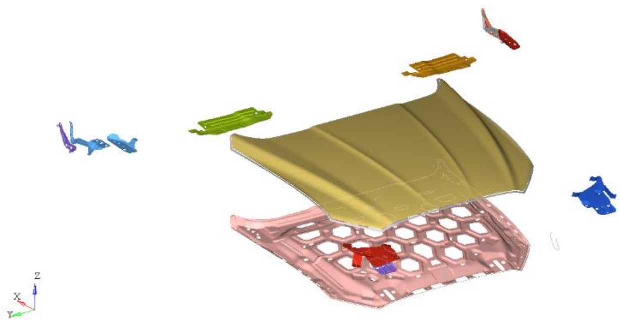

Figure 1. Example of a Hood Assembly in exploded view.

Even though the main function of the hood is to cover the engine compartment it needs to satisfy a defined number of requirements that include the following:

- Appearance: considering the outer hood panel is a visible surface it should be attractive and might be consistent with the product design DNA intended for the targeted market/customers. For this purpose the hood shape, edge lines and the character lines are essential features. Furthermore, the hood needs to maintain excellent fit and finish with the surrounding systems such as fenders, headlamps, cowl covers, and windshield seals among others.
- Customer functional requirements: Customer interaction while opening, closing, washing, and others of this nature are considered for the hood which includes an adequate firmness feel requirement.
- Manufacturing requirements: Most of the parts comprising the system are constructed of sheet metal, formed by a stamping process, then assembled to the body-in-white, and finally painted together. In the paint process, at first the sheet metal body along with the hood and other closures like doors, trunk etc., pass through an 'E-coat' process, where the hood must withstand all possible loads applied from the operator and robots during this period.

An optimization methodology using Tosca Structure.Bead to support the design & development of a vehicle hood assembly, within the constraints of critical timing, lightweight design, low cost and manufacturing requirements is described in this document.

2. Model Description

The goal of the FEA and optimization study is to estimate and optimize the displacement on the most critical zones around the periphery of the hood assembly model under the physical load and constraints conditions of the E-coat process, within the feasibility limits for design, cost, and manufacturing requirements, while not affecting required performance on other structural requirements. An example of the E-coat process is shown in Figure 2.

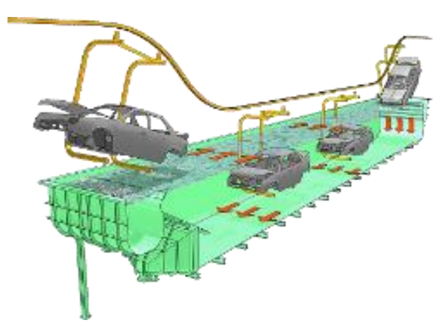

Figure 2. Example of an E-coat process.

Depending on the vehicle architecture, and the paint process/strategy, a rack might support the hood, or it could be supported by using the functional attachments only. For this particular study case the hood is supported on its hinges, with the striker latched in the closed position.

After the vehicle body with the hood passes the E-coat process, the hood hemming adhesive undergoes a change in mechanical properties, due to the curing effect, which is also characterized and included in the material properties on the FEA model.

The analysis was performed with ABAQUS 6.14.2. The parts of the hood assembly including reinforcements are modeled as quadratic and triangular shell-elements, and the connecting elements are modeled as HEX-elements. Contact definition among hood parts is defined. Most of the hood assembly sheet metal parts are simulated as non-linear steel materials.

To assess the displacement of the hood, given the time constraints, the FE model is simplified compared to the complexity of the physical condition, while being detailed enough to capture the effects accurate.

Since for this purpose the deformation is local to the Hood system only, the Body portion is excluded from the analysis. Three translational degrees of freedom constrain the attachment points on hinges and at the striker, which are sufficient to represent the support provided by the body. Gravity load on the Hood, and the change in afore-mentioned mechanical properties of the structural adhesive in the hem are the external loads distributed on the Hood FE model.

3. Processing Initial Static Hood Design Results

As a result from the ABAQUS analysis, the .odb file contains the initial design displacement result. Using a commercial post processor, that reads the format file, allows the user to plot the displacement contour and identify the level of displacement and the areas most relevant to quality requirements that need to be reinforced. By comparing to a defined target, which represents the customer or process satisfaction index, it is ensured that the hood would maintain a quality fit and finish when it follows the next manufacturing stages.

In this case the hood mounting strategy induces more than acceptable displacement on the front corners of the exterior panel. Additional details to the identified root cause are the mounting distance to support points and the corner rotations with respect to the Hood inner panel main structure.

3.1 Initial Traditional Intuitive Countermeasures Proposal

On the traditional approach the engineer’s experience plays the main role in finding a feasible solution. Different initial alternatives are proposed as countermeasures and have to be tested to determine if the undesired displacement conditions can be mitigated.

Traditionally, the first approach is to propose a local reinforcement on the affected area, implications of this potential solution include adding mass where it is intended to improve performance, generate a new part, which generates cost and additional time is needed to incorporate part and joints into the design, therefore is not very likely to be accepted as a formal solution, while it may be the typical first concept solution.

Another design proposal is to up-gage the entire Hood inner panel to increase the stiffness of the whole part, and reduce the displacement on the corner. But since this is a large panel, the cost/weight increase is significant, and the additional part weight will also further affect stiffness performance due to the increased gravity load on the affected area.

Other potential ‘band-aid’ solutions are stiffener patches, which are constructed of composite materials, normally made of one layer of adhesive resin and a second layer of glass fiber material.

While this option was simulated and included on the base hood model the performance improvement was unsatisfactory. The study of internal prior art/solutions along these lines did not yield any effective solutions either.

The other option is to modify the hood geometry on the affected area on an intuitive and experience/engineering judgment. Based on trial-and-error iterative method the design approaches sequentially to a desired objective. This method may or may not be effective, due to the complexity of this requirement to other related requirements. In this case all the design proposals tested were not providing significant improvement.

4. Tosca Structure.Bead Hood Optimization Description

The bead optimization work which the team needed to have in order to satisfy the hood requirement would also need to satisfy CAE time/efforts related requirements such as (but not limited to) the following:

1. Simplicity: once the initial deck is created for this specific study case it should be simple to use with the minimum amount of input and effort.

2. Flexibility: optimize one or more parts and/or part surfaces from any sheet metal assembly.

3. Agility: the optimization should be responsive enough to support analyses time constraints and deliver effective countermeasures within short iteration.

4. Repeatable: allow less experienced engineers to perform the optimization in the future.

5. Single objective: reduce complexity to focus on immediate problem solving.

6. Low cost solution generation: geometry that minimizes impact on tooling cost.

7. Robustness of solution: meet the expected performance while not degrading other related functional and performance objectives.

8. Input and set up: minimum information and effort required

Also, the optimization process involves manufacturing, design, packaging and compatibility constraints between different systems' functional requirements which are out of the scope since team rationale and cross-functional agreements are valid to satisfy constraints and exclude them from the computed optimization process.

The team identified that the Tosca Structure.Bead optimization solver satisfied the design and working level requirements and a template deck was generated for the ABAQUS load case.

The Optimization was performed on the Hood inner panel exclusively because it is the main contributor to the local stiffness. Two separate bead optimization were performed. One in the local affected corner area, and the second one on the remaining feasible surfaces in case stiffening up the corners was not sufficient to achieve the objective.

The optimization case included the following information:

1. Input file name.
2. Bead optimization definition.
3. Design response: non-linear, strain energy on the design elements.
4. Bead Height.
5. Objective Function: maximize stiffness by minimizing strain energy
6. Constraint on bead height
7. Provide smooth surfaces for output visualization

5. Tosca Structure.Bead Hood Optimization Results

Tosca optimization results on the local area is provided in Figure 3. The blue shapes shown are the resultant beads Tosca suggests in order to maximize the local area stiffness under the ABAQUS defined load case. The main advantage of the result obtained is the bead geometry definition, direction, orientation and distribution.

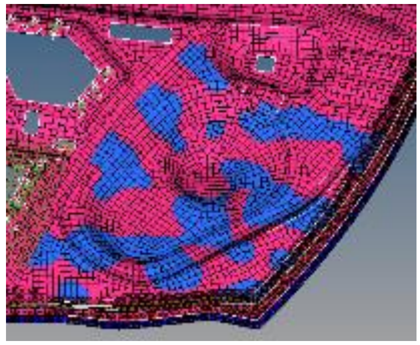

Figure 3. Tosca Structure.Bead Local Area Result.

The result of the complete Hood inner panel was gathered for reference, there were some additional sensitivity studies run to prepare additional non-intuitive solutions in case reinforcing the local area was not satisfactory. It is worth to mention that the result of local optimization was the same as in the complete panel focusing on the local area.

5.1 CAE conceptual countermeasures proposals from Optimization Results

The optimization results obtained serve as a start for developing conceptual CAE designs on the initial model and to improve the displacement condition.

Even though the optimization was conducted on the local corner, some local surfaces were not available to be modified using beads, the principal constraint being the circular surface that contacts the front bumper, which needs to support the complete hood assembly during close operation and during hood slamming events.

The first iteration is shown in Figure 4. The displacement condition met the expectation level to satisfy the stiffness requirement. This represented a high success since right from iteration 1 the performance level could be achieved.

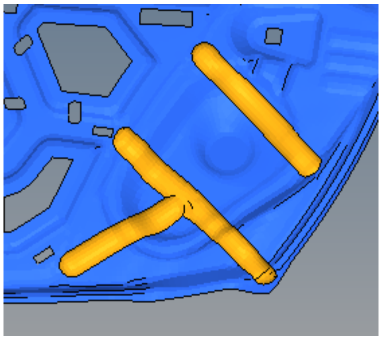

Figure 4. Iteration 1 with the use of CAE Tools.

The team was aware that of the potential difficulties that iteration 1 may have to reach final design since stamping feasibility and packaging constraints were not checked/included in the optimization, in order to keep as simple as possible the optimization process, and with the mind set of verifying them through cross-functional communication.

Once those constraints were better understood, the team came up with iteration 2 shown in Figure 5, where performance degraded slightly from iteration 1 but was still meeting the requirement.

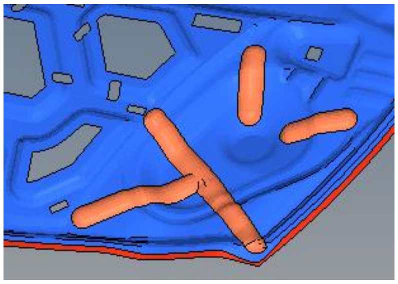

Figure 5. Iteration 2 with the use of CAE Tools.

Following this, the team generated a CAD model for the proposal that could be incorporated in final design, as shown in Figure 6. The expectation was that when the proposal CAE solution goes through the subsequent design & manufacturing validation process and into final CAD it could very well degrade even more in performance than the initial CAE generated design. But the initial CAE proposed design was robust enough that the final design still met the desired displacement level and therefore satisfied the requirement.

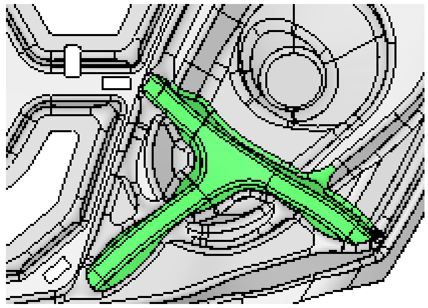

Figure 6. Final Front Corner Design.

6. Concluding Remarks

As the reader may observe, an iterative process from the initial design which does not satisfy the established requirement to generating feasible design solutions that satisfy performance requirements, and to incorporate them into the final product takes a lot of effort and is time consuming.

Tosca Structure.Bead is proven to be a effective tool in the generation of optimized solutions that meet current industry challenges such as but not limited to time constraints, weight and cost targets, along with process simplicity, for automotive and other applications that use sheet metal, within a hyper-efficient product development process, representing a high value tool.

7. References

1. Tosca Structure Documentation, Version 8.1, Dassault Systémes Simulia Corp., Providence, RI.

2. "ABAQUS Documentation," 2014, Dassault Systèmes, Providence, RI.