DENTING SIMULATION OF BIW EXTERIOR PANEL OF VEHICLE

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Abstract - Present study deals with the finite element analysis (FEA), specifically denting simulation of upper rear bumper of vehicle to analyze the denting resistance of this plastic panel. This study involves the 3D scanning of upper rear bumper (plastic panels) of vehicle in laboratory for CAD model, tensile testing of test specimens for stress-strain material properties, FE model built-up for analysis using preprocessor, computer aided engineering simulation of this panel against denting using solver, analysis of simulation results using post-processor and physical denting test in laboratory on weak positions extracted from the denting simulation. Various commercially available finite element analysis tools like pre-processor, solver and post-processor are used in this analysis study. At the end of this study comparison of the simulation results with that of physical test results is performed to establish percentage correlation. The comparison of simulation results with that of experimental results shows that physical denting test results matches with FEA simulation results with small deviation.

Key Words: Finite element analysis, Body-in-white, Denting, Pre-processor, Solver, Post-processor

1.INTRODUCTION

Automotive manufacturers focusing more and more on reducing weight of the car to make the car fuel efficient in order to cater the demand of time. In reducing the weight of vehicle, weight reduction of these exterior skin panels (ex. hood panel, roof panel, door panel, fender panel, side panels, tailgate panel etc.) of vehicle plays important role. Steel manufacturing companies are developing high strength and durable steels for automotive companies like Dual phase steel and TRIPS steels. These materials are having high strength and good formability which is very important for automobile exterior panels. Automobile manufacturing companies are also looking for plastic panels to achieve the desired objectives. Strength of this plastic panels also plays important role in material selection. Denting strength of these panels verified by denting test. Earlier automotive manufacturers were used to perform denting test on completely assembled panels which involves huge cost of rework. In recent years due to huge advancement in computer technology it becomes possible to perform the denting test using finite element analysis software's.

"Denting Simulation of Body-In-White Exterior Skin Panels of Vehicle" involves 3D scanning of upper rear bumper for CAD model, pre-processing which involves geometry cleanup, applying boundary conditions and model set-up for analysis, this also involves preparation for material card for solver, modal analysis for ensuring full-proof connections, raster simulation for finding weak positions, denting simulation using finite element analysis software's and experimental denting test. Also involves comparison of simulation results with experimental results to establish the percentage correlation.

2. REVIEW ANALYSIS

X. M. Chen and M. F. Shi et al. [1] performed denting, forming and spring-back simulation on stretched dome using LS-DYNA software for three different materials and concluded that fine mesh in denting area and 1mm element size of indenter gives more accurate results. Also forming simulation result shows significant impact on dent resistance.

Danielle Zeng and Cedric Xia et al. [2] performed denting simulation for two different materials as BH210 and DP500, incorporating forming and bake hardening effect for fender panel of car. They concluded that DP500 material is better than BH210, even more down-gauging is possible if panel stiffness is not considered to that extent. Also forming and bake hardening effect need to be considered for more accurate results.

M. Heckmann, A. Birkert, M. Scholle, M Sobhani, B. Awiszus and H. Weiland et al. [3] presented one approach for increasing denting stiffness for exterior body panels of automotive cars based on induction of intrinsic stresses. They have concluded that superposition of induced stresses is a pragmatic method to increase denting resistance of exterior panels.

Ilker Bahar et al. [4] Performed static dent resistance test of automotive exterior rear bumper by finite element method in simulation software as well as physically in test lab. Exactly matching loading points both in physical test and finite element simulation and correctly defined material properties gives most accurate results.

Kentaro Sato, Yuuchi Tokita, Moriaki Ono and Akihide Yoshitake et al. [5] performed denting simulation of automotive exterior panel for different material considering continuous yielding behavior and forming effect. They have observed that pre-strained material had continuous yielding behavior, which reduces the actual yield stresses.

S. Sriram, J. G. Speer and D. K. Matlock et al. [6] performed denting simulation on geometrically modified panels with similar material used for automotive exterior panels. They concluded that, panel thickness and dominantly radius of curvature (geometric modification) have the most significant effect on panel stiffness. While panel size and boundary conditions have very small influence.

G. P. DiCostanzo, D. K. Matlock and R. P Foley et al. [7] Evaluated denting resistance for AKDQ (Aluminum Killed Drawing Quality), Bake-Hardenable and IF Re-phosphorized steel sheets in both normal and pre-strained condition. On the basis of experimental and simulations results they concluded that, there is substantial increase in dent resistance of steel sheets in pre-strained condition compared to normal condition.

Ming F. Shi, David J. Meuleman, Christine L. Alaniz and Stephan J. Zurdosky et al. [8] have investigated the effect of pre-strain on static dent resistance of automotive exterior panel. Based on this investigation they concluded that, static dent resistance of automotive body panels not only depends on geometry and material properties of panels but also on the strain level in the panel. Also concluded that dent resistance can be significantly improved by a small increase in strain level of panel.

3. SOLUTION METHOD

In this denting simulation, basically non-linear finite element analysis method is used, because material is loaded beyond the yield limit and also non-linear plastic strain data is used for analysis. Due to which it falls under material non-linearity problem domain.

Here in this analysis, Implicit solution scheme is used instead of Explicit time integration scheme because of less sensitive to size of time step, stability and greater accuracy.

In this, the solution of upcoming step is dependent on the earlier step solution, thus the final solution is result of solutions of multiple steps. Basically, Newton–Raphson Method is used to solve the equilibrium equations at each step. To find out the solutions, Taylor series approximation method is used which was proposed by Newton-Raphson. The motivation behind using this technique is convergence rate, which is very good when we compare with Gauss elimination and Gauss Siedal method.

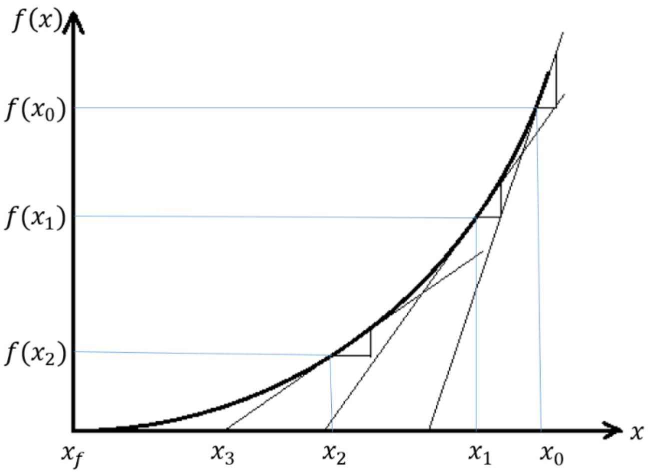
The Newton-Raphson's formula for solution of single step is,

$$x_1 = x_0 - \frac{f(x_0)}{f'(x_0)}$$

This formula is repeated for each time step until desired accuracy is achieved. The integrated formula for multiple time steps is as follows,

$$\mathrm{x}_{\mathrm{n}+1} = \mathrm{x}_{\mathrm{n}} - \frac{f(x_n)}{f'(x_n)}$$

From the below mentioned graph 1 of solution convergence, we can observe that with each time step we are moving towards accurate solution.



4. METHODOLOGY

4.1 CAD MODEL

Upper rear bumper is main component of study. 3D scanning is performed in laboratory and scanning dimension data is extracted. Based on this scanning data solid model is prepared using CAD modeling software. **Figure 1** shows the prepared CAD model of upper rear bumper.

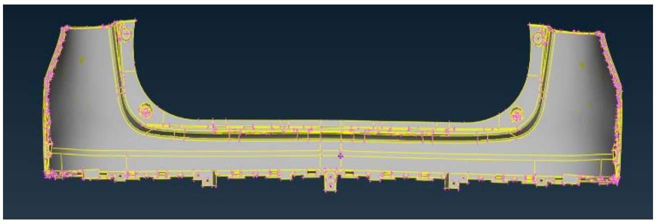


Figure 1: Upper Rear Bumper

4.2 PRE-PROCESSING

In pre-processing, geometry clean-up is performed using pre-processing software. Geometry clean-up involves removal of sharp edges, removal of collapsed edges, removal of needle faces, removal of overlapped faces, removal of cracks etc.

As thickness of the panel is very less compared to length and breadth, analysis is need to perform shell model. For this purpose, mid-surface of this CAD model is extracted. **Figure 2** shows the extracted mid-surface of panel. The shell model is then meshed using pre-processor, which involves mixed mesh of quad and tria elements with average 3 mm mesh size all over. **Figure 3** shows the meshed panel.

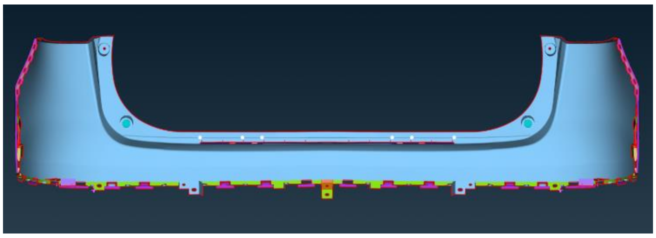


Figure 2: Geometrically cleaned model

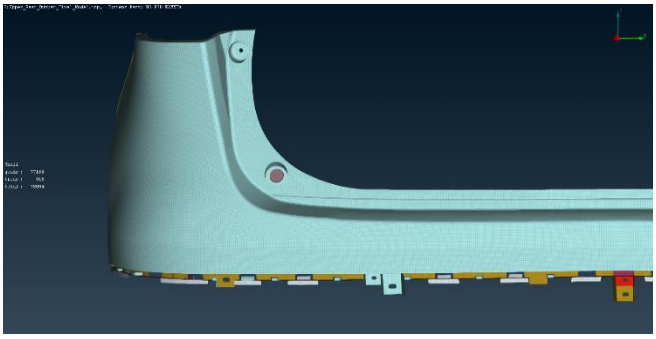


Figure 3: Meshed Model

Table 1: Meshing Details

Sr. No.	Element type	Number of elements
1.	Quads	77168
2.	Trias	916
	Total	78084

4.3 BOUNDARY CONDITIONS

As per the connections provided in actual vehicle, connections were modelled on the panel using pre-processor. Bolt

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connections, snap fitting rigid connections were provided using RBE2 and RBE3 (rigid body elements) as shown in **figure 4**. Degrees of freedom constrained corresponding to connections in actual vehicle. Following pictures shows the connections modelled using pre-processor.

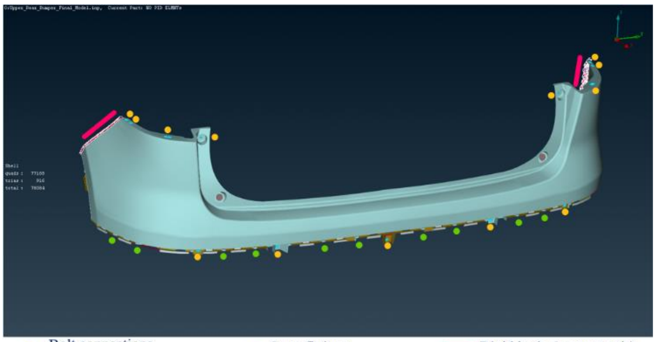

Figure 4: Boundary Conditions

5. MATERIAL PROPERTIES

Total five test specimens are cut from the upper rear bumper panel using water jet cutting in laboratory as per the ASTM 638 plastic standards. **Figure 5** shows the actual test specimen.

Figure 5: Test Specimen

Tensile test is performed to get the non-linear material properties for five specimens. From all these data, stress-strain curve is plotted and average of all the stress-strain curve is taken to create the single stress-strain curve and corresponding stress and strain values considered for material card. As plastic panel is considered, secant modulus is taken out by assuming 0.85% desired engineering strain. Upon that true stress-strain values calculated to prepare non-linear plastic strain data for non-linear analysis. Also, density and poisson’s ratio is calculated from available data. Graph II shows the average stress-strain curve. **Figure 6** shows material testing setup.

Figure 6: Test Setup

6. MODAL ANALYSIS

Standard practices show that modal analysis is used to find out resonance frequencies and mode shapes to understand the mode behaviors, but here it is performed to check whether the boundary conditions and material properties provided are correct or not. **Figure 7** shows the twisting mode shape with full-proof connections.

Figure 7: Modal Analysis

7. RASTER SIMULATION

Raster simulation is performed to identify the probable weak locations on the panel by putting the defined load on all the nodes for identification of nodes with large deflection. For that purpose, the outer surface of panel exposed to probable denting is selected. The raster node set of all the nodes exposed to denting is prepared by keeping 50mm margin and 30mm raster size using pre-processor. Also load case file and stamp detail file is prepared.

The geometry file which involves nodes, elements and connections is extracted from pre-processor, shell properties file is also extracted from pre-processor, linear material card is prepared using material properties data, also stamp file which involves material properties data, shell and solid element data for stamp is prepared.

As the panels with geometric features is comparatively stiff than the surfaces without geometric features, surface without geometric features is selected for the denting simulation and denting test.

By incorporating geometry file, properties file, linear material properties file, contacts file and load case file, raster simulation deck is prepared. Upon solving the raster simulation using solver, the data of deflection and stiffness is extracted. **Figure 8** shows the model prepared with node set and probable positions selected for detail denting.

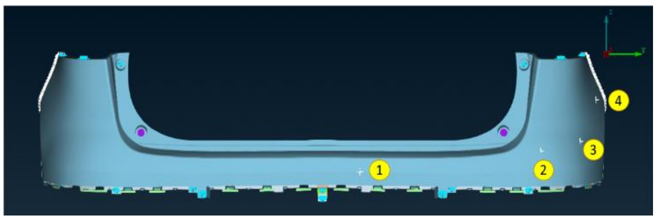

Figure 8: Raster Node Set for Detailed Denting

8. DETAILED DENTING SIMULATION

In detailed denting simulation, the 17 probable weak positions identified by putting criteria of maximum deflection and minimum stiffness. On this selected positions, detailed denting simulation is performed. In this, basically rigid stamp of 30 mm diameter with 100N load is applied on each selected weak positions and behavior of panels for deflection is observed. Detailed denting simulation is performed using non-linear material data. **Figure 9** shows the model setup for detailed denting simulation with load applied with stamp.

The detailed denting simulation deck is prepared, by incorporating geometry file, properties file, non-linear material properties card and stamp file. Then this detailed denting simulation solved in solver which basically solves the differential equations.

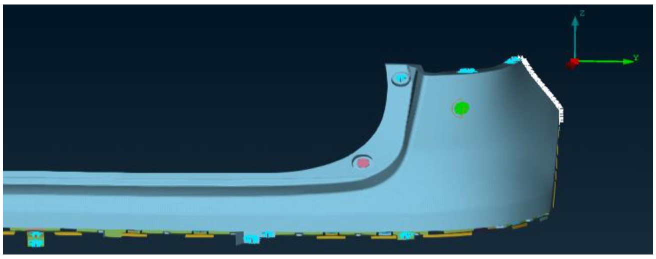

Figure 9: Detailed Denting Simulation Model

8.1 DETAILED DENTING SIMULATION RESULTS

Table 2: Simulation Results

Sr. No.	Position Number	Elastic Deformation (mm)	Plastic Deformation (mm)
1	Point 1	6.92	0.33
2	Point 2	8.57	0.08
3	Point 3	8.00	0.07
4	Point 4	15.91	0.65

9. PHYSICAL DENTING TEST

The physical denting test on upper rear bumper is performed in laboratory. The similar setup is prepared like simulation setup by providing connections using fixture and 30 mm diameter rigid stamp with 100N load is applied and behavior of panel against deflection is observed. Figure 10 shows the physical denting test setup.

Figure 10: Denting Setup

9. PHYSICAL DENTING TEST RESULTS

Table 2: Physical Test Results

Sr. No.	Position Number	Elastic Deformation (mm)	Plastic Deformation (mm)
1	Point 1	8.17	0.01
2	Point 2	8.20	0.24
3	Point 3	10.78	0.01
4	Point 4	18.30	0.72

10. CONCLUSIONS:

The denting simulation of upper rear bumper is performed considering non-linear analysis and physical denting test is performed in laboratory. From the comparison of simulation results and physical denting test results can conclude that:

1. Exactly matching loading points in both simulation and physical denting test gives more accurate results.
2. Structural parts of BIW connected to the denting panel should also consider in both simulation and physical denting test, for more accurate results.
3. Providing accurate material properties increases the accuracy of results.
4. Consideration of variable thickness in simulation improves the results accuracy.
5. The small deviation in simulation and physical test results is due to structural parts of BIW are not considered in simulation and also, snap fitting connections are not modelled in simulation as well as in physical denting test. Consideration in simulation would improves the results.

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