New Finite Element Model for NHTSA Impact Barrier

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Abstract

The US Federal Standard for Side Impact Protection (FMVSS 214) uses a deformable barrier and defines the dimensions and materials of the barrier, as well as the crush strength of the aluminium honeycomb parts in the main block and the bumper. This deformable barrier is also used for rear impact according to the updated FMVSS 301. This paper represents the methodology to create the advanced Finite Element model of Cellbond's NHTSA barrier and validation through experimental test data. The explicit LS-DYNA® was used to analyze the model while number of static compressive tests performed at different angles to characterize aluminum honeycomb Material Cards. A strain-rate scale factor curve is defined to simulate the dynamic stiffening in the aluminium honeycomb during the analysis. Adhesive properties are also obtained using Climbing Drum, T-Peel, Tensile and Plate Shear test results. The preliminary component tests generated a good correlation with FE outputs and to validate the barrier model, similar impact tests were performed in LS-DYNA environment respecting to three experiments Flat-Wall, Rigid-Pole and Rear-Armature tests. In all assessments, the barriers were mounted on a moving trolley and were tested at certain speeds. The Final comparison on overall results represents a good correlation between test data and CAE results for all tests.

Keywords: NHTSA, FMVSS 214, FE Analysis, Cellbond Barriers

Introduction

Federal Motor Vehicle Safety Standard (FMVSS) 214, "Side Impact Protection" was amended in 1990 to assure occupant protection in a dynamic test that simulates a severe right-angle collision [1]. It is one of the most important and promising safety regulations issued by the National Highway Traffic Safety Administration (NHTSA). It was phased into new passenger cars during model years 1994-97. In 1993, side impacts accounted for 33 percent of the fatalities to passenger car occupants. The current FMVSS 214 is the culmination of many years of research to make passenger cars less vulnerable in side impacts, and especially to reduce fatality risk to the nearside occupant when a car is struck in the door area by another vehicle - the configuration responsible for the majority of side-impact fatalities. The main core of this barrier face assembly is to be constructed from aluminum honeycomb having crush strength of 310 ± 17 kPa (45 ± 2.5 psi) and the bumper is constructed of honeycomb 1690 ± 103 kPa (245 ± 15 psi) sandwiched between 3.2 mm (0.125") thick aluminum plates (Figure 1).

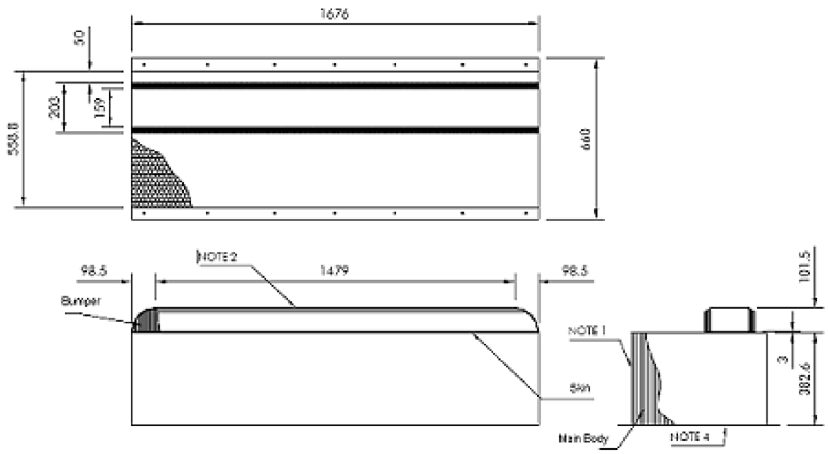


Figure 1. NHTSA Barrier Parts and General Dimensions

The connectivity between individual parts is created using a specific PU adhesive and the overall mass of the barrier is approximately 25 kg.

Finite Element Model

Numbers of reliable techniques have been developed to simulate the aluminuium honeycomb crush behaviour [2, 3], however, it becomes time-consuming to create and solve complex geometries with various boundary conditions. Recruiting the Modified-Honeycomb-Material (Mat 126) card and modeling the honeycomb parts with solid elements creates an efficient way to solve the model/s. However, accurate material data in different formats are needed. The yielding function technique has given well-mannered results in investigations of IIHS [4] and AE-MDB [5] crash barriers. This method also represents an appropriate performance on honeycomb composite panels subjected to dynamic headform impact [6]. In this method the yield stress of honeycomb is a function of different parameters [7] as described in equation 1.

$$\sigma^{y}(\varphi,\varepsilon^{vol}) = \sigma^{b}(\varphi) + (\cos\varphi)^{2}\sigma^{s}(\varepsilon^{vol}) + (sin\varphi)^{2}\sigma^{w}(\varepsilon^{vol}) \qquad \text{(Eq.1)}$$

in which

φ = Section angle with the strong axis (Fig. 3)

$\sigma^{b}(\varphi)$ = Yield stress as a tabulated function of section angle

$\sigma^{s/w}(\varepsilon^{vol})$ = Stiffness as a tabulated function of volumetric strain

Figure 2, illustrates the compressive test procedure for different angled sections of the honeycomb blocks. The composite material used in the static tests was Cellbond’s 1.6 3/8 5052 and 5.2 1/4 3003 aluminum honeycomb and the block dimensions were 200 mm x 180 mm x 50 mm which was tested at speed of 10 mm/min. Plot (1a), shows the typical value of yield stress versus cut section angle in NHTSA barrier’s main honeycomb blocks. In the test the highest compressive stress was measured in zero degree (strong axis) and as the angle increases, the compressive stress decreases. The static crush strength of honeycomb drops down significantly after 60 degrees and the 35 degrees cut section represents almost half of normal core strength.

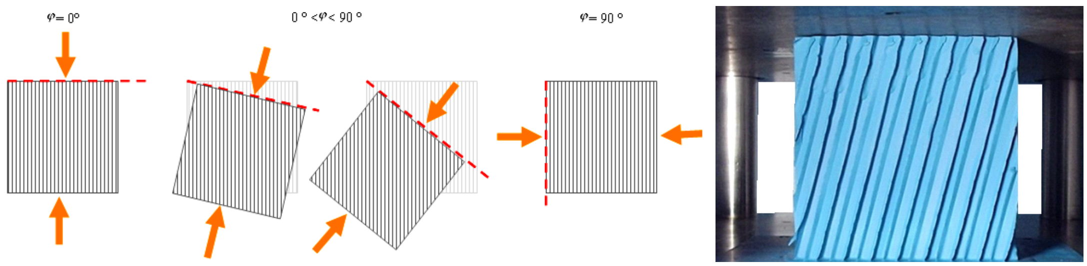
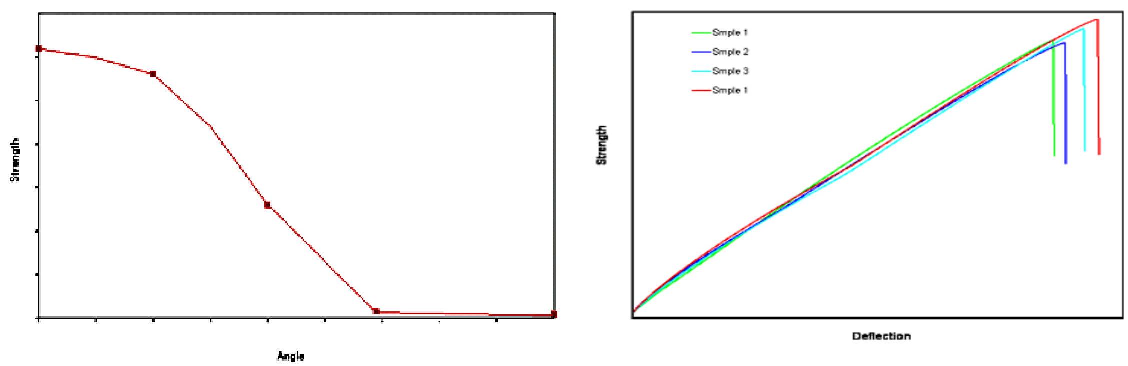


Figure 2. Static angled compressive test procedure

A strain-rate scale factor curve was also defined to simulate the dynamic strengthening status in honeycomb material model. The Arup-Adhesive (Mat 169) material card was developed to simulate the connection between parts in which the results from Climbing Drum, T-Peel, Tensile and Plate-Shear tests were used to get proper card data. Plot 1b, shows the results from Solid-Solid tensile test schematic results.



a) Compressive stress vs. cut section angle b) Solid-Solid tensile test results

Plot 1

Null material shell elements with reasonable thickness were supplied through solid layers in main body and bumper part to enhance contact control criteria during crash. FE shaded views of NHTSA barrier model are shown in figure 3.

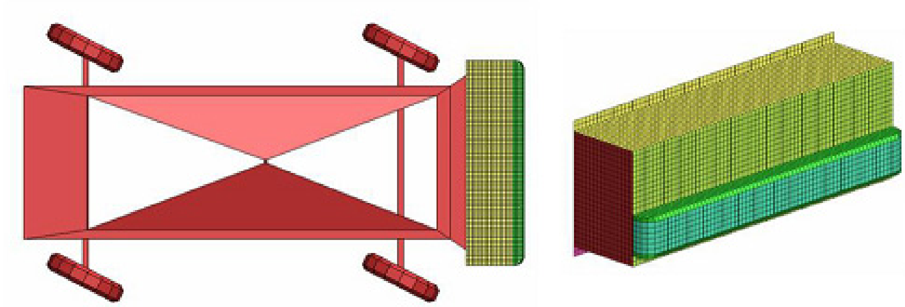
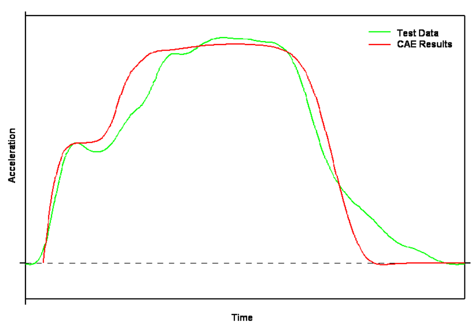


Figure 3. NHTSA FE Model

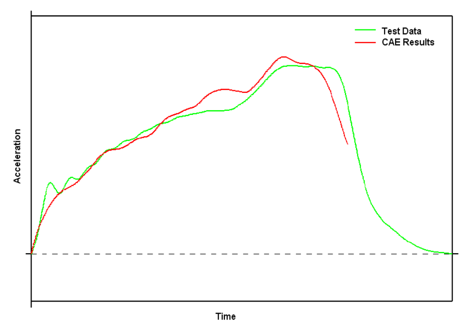
The LS-DYNA default Hourglass control has been used to monitor the element energy on honeycomb parts due to the use of one point corotational solid on honeycomb parts and a control card managed the relevant time-history data to investigate the energy flow in individual components and contacts.

Experimental Tests and Results

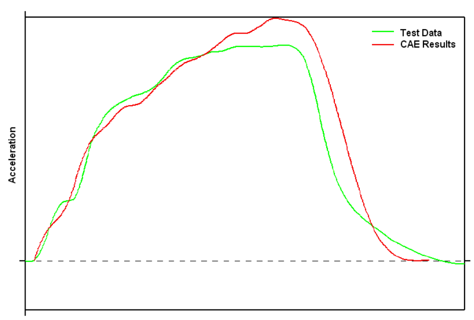
To evaluate and verify the accuracy of the created model, the dynamic analysis was based on four experimental test results. The overall mass of the trolley including the barrier was 1367 kg and front and rear track width is 1880 mm. Flat Wall test represents the crush performance of NHTSA barrier in a collision with load-cell surface. The barrier was mounted on a moving trolley and tested at 8 m/sec (29 km/h). In the Pole test, the NHTSA barrier was subjected to a symmetric crush with a rigid vertical pole in which test speed was 8 m/sec (29 km/h). The Rear-Armature impact test represents an offset longitudinal crash with a combination of rectangular and pole impactor. The test was carried out at 8 m/sec (29 km/h) test speed. The Half-Wall test used a flat impactor to crush only half of the barrier through out the height with the test speed of 8.2 m/sec (30 km/h). The overall mass of barrier and trolley was1367 kg in tests and the row data were obtained from accelerometers installed in the centre of gravity of the trolley which was located in 1123 mm behind the front axle and 500 mm above the ground. In this research the assessment was stabilized on accelerometer output and the local motion side acceleration component vector was considered as the assessment module. In FE model, the accelerometer element was defined on the trolley's rigid body to record time-history data within specified time steps. Plots 2(a-d) illustrate a comparison of experimental test data and FE analysis for Rigid-Wall, Pole, Rear-Armature and Half-Wall tests. The deformed barriers are also compared with CAE results in figures 4(a-d).



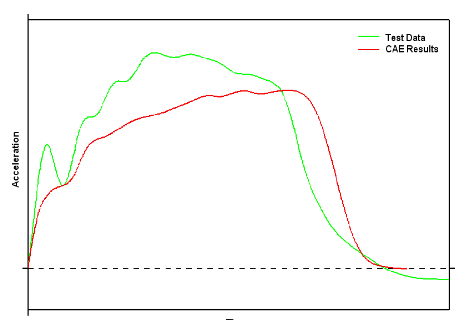
a) Flat-Wall test



b) Pole test

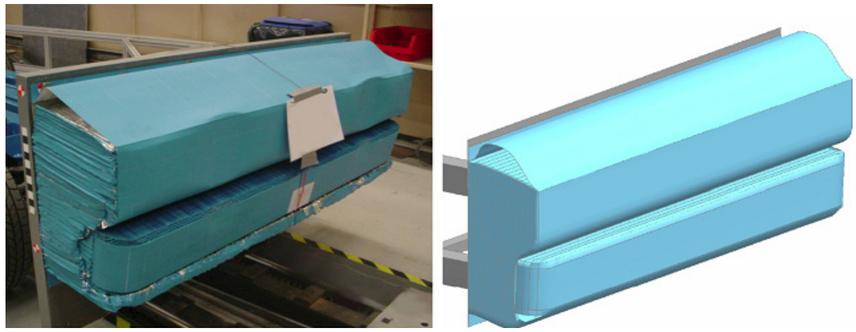


c) Rear-Armature test

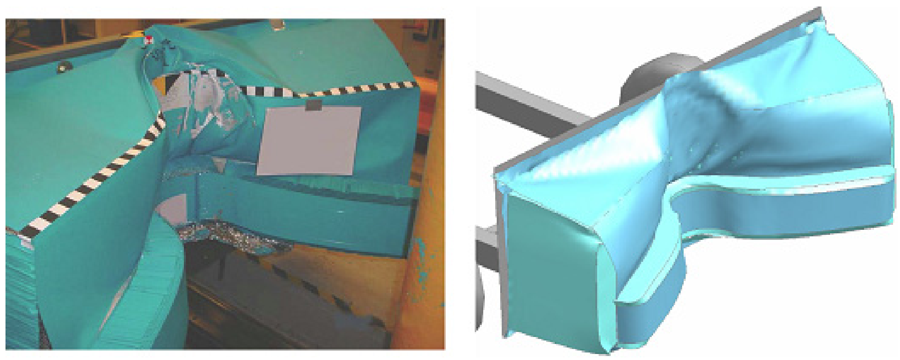


d) Half-Wall test

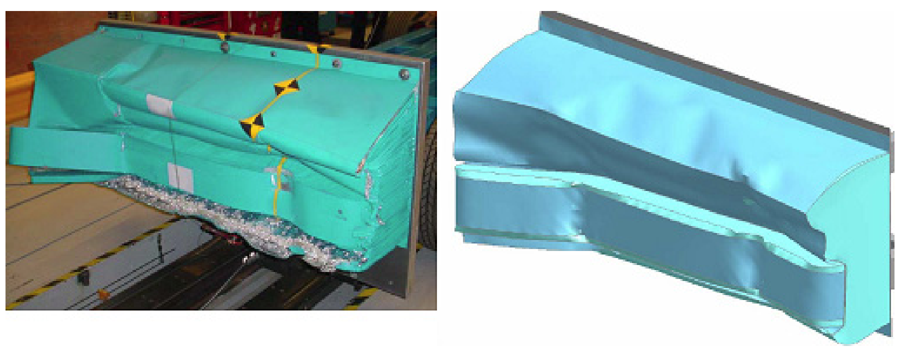
Plot 4. NHTSA model evaluation test results vs. CAE



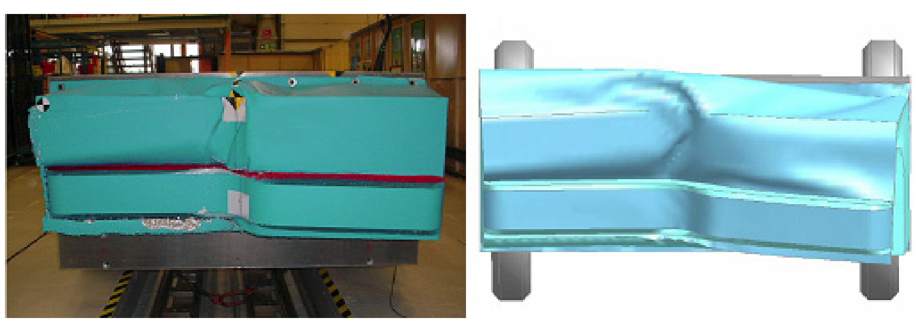
a) Flat-Wall test



b) Pole test



c) Rear-Armature test



d) Half-Wall test

Figure 4. NHTSA model evaluation tests

Discussion

Plots 4(a-d) show that the model creates accurate outputs in terms of numerical output comparing to the experimental test results in all test configurations. The model appears softer in Half-Wall, however, this seems negligible as the graph follows the general shape of the experimental test result and in other tests good correlations have been achieved. Another important observation in this investigation is that, the collision time and thus the crash distance is similar at test and CAE despite the structural complicacy. Another notable outcome of the analysis is the existence of the similar deformation pattern and crush mode in both tests. In the Flat Wall test; stroked pattern and trolley travel distance appear the same within the FE model and the backend of all honeycomb blocks remain uncrushed as it was noticed in the experimental result. The analysis also produced a desired crash pattern in the Rigid Pole, Rear-Armature and Half-Wall tests and simulates an acceptable shear performance between bumper, main body and impactors. Using Null elements between solid layers helped to control internal contact and improved the structural behaviour under local shear applications.

Conclusion

Analysis of the data for NHTSA model shows a good numerical and visual correlation between FE model and experimental investigation for all test configurations. The yielding function technique to define the MAT 126 properties, in association with the multilayer segment configuration encompassing approximate strength on each layer and strain rate gives acceptable results. Also, the stiffening curve contributed a suitable performance and gave satisfactory output compared to the experimental test data. Implementing the Null shell elements with a reasonable thickness within solid layers gave the ability to model the element penetration and thus negative volume errors during shear performances. The developed technique is a superior technique to regular non-linear analysis since the convergence time is reduced a great deal.

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