Finite Element Modeling of Aluminium Honeycomb with Variable Crush Strength and Its Application in AE-MDB Model

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Abstract

Aluminium honeycomb blocks are often to gain differentiated crush strength pattern to represent variable behavior while subjected to static/dynamic deformation. Current article demonstrates the methodology to validate modeling techniques and implementing in a finite element model for the Advanced European Mobile Deformable Barrier (AE-MDB). AE-MDB v3.9 side impact barrier has been investigated in present paper. The FE model is then examined using experimental data from a set of full-scale tests. Component tests have been designed and performed to establish the material characteristics for the FE model to maintain the crush strength pattern within the specified design corridors. The model then has been analysed using LS-DYNA© under certain boundary conditions according to the test specifications and the results have been compared to the physical test data. The barrier has been subjected to the Flat-Wall and Pole tests while the obstacles were blocked against the barrier on a mobile trolley. The methodology is then certified through comparison of the deformation pattern and numerical information with the experiments.

Keywords: Side Impact, Crash Barriers, AE-MDB, LS-DYNA, Finite Elements

1- Introduction

The development of the Advanced European Mobile Deformable Barrier (AE-MDB) v3.9 was started by EEVC WG13 during 2001 in support of European Governmental contributions to IHRA (Ratingen, 2003 and Ellway, 2005). The new barrier was distinguished from the Regulation 95 MDB. The EEVC WG13 proposal resulted in a specification of the AE-MDB v2 which initially APROSYS planned to evaluate. Some modifications on part stiffness were carried out later to make the barrier more representatives with respect to proposed applications and demands (APROSYS, 2006). The new AE-MDB barrier was named v3.9 and had reduced stiffness in the lower row resulting in a subsequent global strength reduction (Graph 1).

Blocks D & F of V3.9 have %45 less strength compare to the same blocks in the v2 barrier, and block E in the v3.9 barrier has 40% less stiffness compared to blocks D & F of the v2 barrier. The overall stiffness of the barrier corridors for V2 and v3.9 (without the beam element) are compared in Graph 1.

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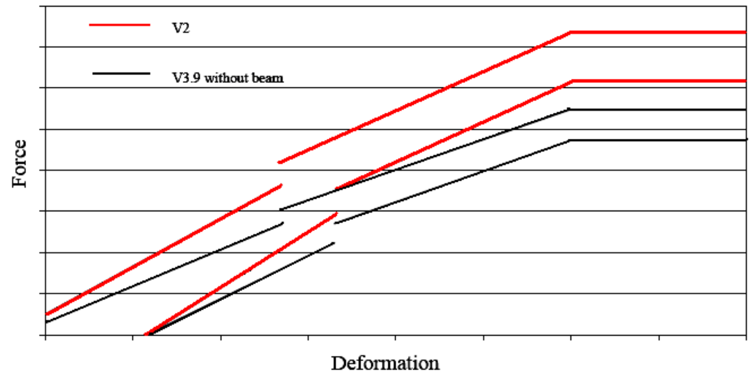

Graph 1. Comparison between v2 and v3.9 barrier strength corridors

This paper represents the terminology to simulate and validate aluminium honeycomb blocks used in AE-MDB where the crush strengths do not follow a consistent horizontal plateau against the deformation. The technique has then been implemented in the new FE model of the AE-MDB v3.9 side impact barrier besides the specific assumptions to generate the boundary conditions. Cellbond AE-MDB barrier is investigated to produce the advanced FE model while experimental results from Flat-Wall and Offset-Pole tests are used to evaluate the accuracy of the model.

AE-MDB side impact barrier represents the typical frontal stiffness of a modern vehicle (Graph 2) in a car to car side collision experiment and stands for the bullet car during the side impact tests. Unlike most of the other common car crash test barriers, The AE-MDB contains six separate honeycomb blocks (excluding front bumper) with cladding skin and rigid honeycomb bumper (Figure 1). Each block has individual stiffness characteristics vs. deformation. However, the barrier is symmetric about an imaginary axis through the center of the barrier. The blocks should meet the strength criteria defined individually within the corridors. The main blocks are covered with a 0.5mm aluminum skin and the bumper honeycomb piece is significantly stiffer than body parts, is located in front of main cores. The bumper includes two 3mm aluminum plates at both sides and its corners are cut to follow the geometrical characteristics of the main body.

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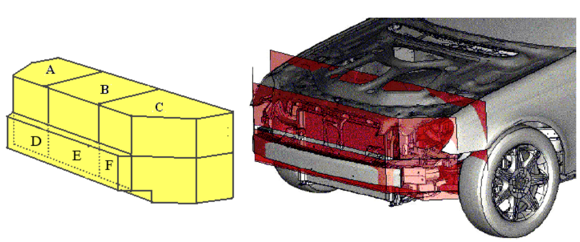

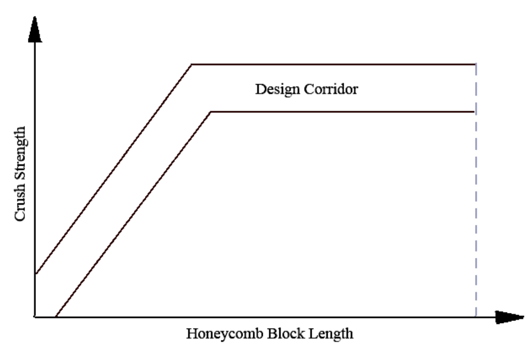

Figure 1. AE-MDB compared to the front part of a car

Graph 2. Typical design corridor for AE-MDB

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2- Material Data and Verification

Although a number of credible methods are available to simulate honeycomb crush behaviour (Asadi, 2005 and Yamashita, 2004), it is time-consuming to create and solve complex structures with aluminium honeycomb and non-uniform geometries with various boundary conditions. Using the Modified-Honeycomb-Material (Mat 126) card and modeling the parts with solid elements and precisely defined material properties is an effective method to solve such models. The yielding function while using solid elements has shown relatively accurate results in analyzing deformable barriers (Kojima, 2005 and Moisey, 2002) . In this method the yield stress of honeycomb is a function of different parameters [8] as described in equation 1.

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

in which φ is the section angle with the strong axis, $\sigma^{b}(\varphi)$ is the yield stress as a tabulated function of section angle and $\sigma^{s/w}(\varepsilon^{vol})$ represents the stiffness as a tabulated function of volumetric strain. Figure 2, illustrates the test procedure for different angled section of the honeycomb blocks. The aluminium honeycomb blocks used in these tests where from Cellbond's 1.8 ¾ 3003 core and random samples were cut to run the experiments. The block dimensions were 200 mm x 180 mm x 50 mm which were tested quasi-statically at speed of 10 mm/min. Graph 3, shows the typical value of yield stress versus section angle in different etched layers of AE-MDB honeycomb blocks.

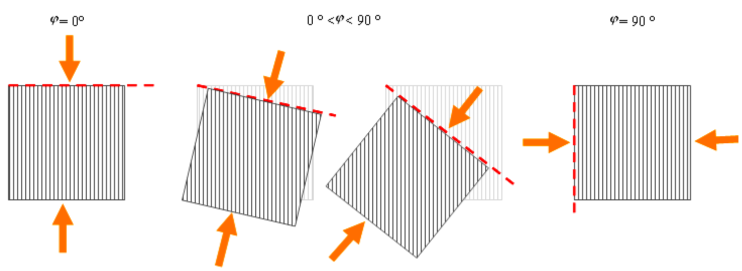
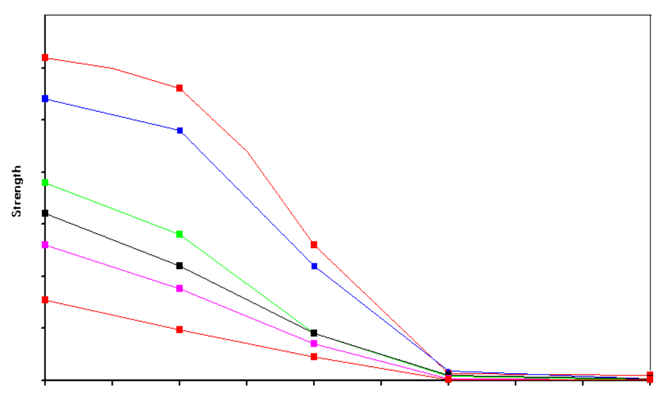


Figure 2. Static angled compressive test procedure



Graph 3. Compressive stress vs. cut section angle

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To examine the robustness of the material properties, a series of angled impact tests on the normal honeycomb blocks was performed. In these tests the samples were obtained from the AE-MDB honeycomb core and blocks. The specimens were fully restrained to the support jig and the off-axis tests were maintained at two orientations (α) for 15° and 30° (Figure 4). The Impactor mass was 102 Kg for 15° test whereas it was maintained 108 Kg for 30° test. . The average test speeds were 6.9 m/sec and 6.1 m/sec respectively.

The numerical results for the component tests are shown in Graph 3. The CAE outcomes present relatively lower magnitude at the later stages of the crash, however, this does not seem to be significant and the graphs follows the general path for the experimental data and create a reasonable approximation of the honeycomb crush strength against deformation. The results in 30° simulation are closer to the physical test results and make better correlation.

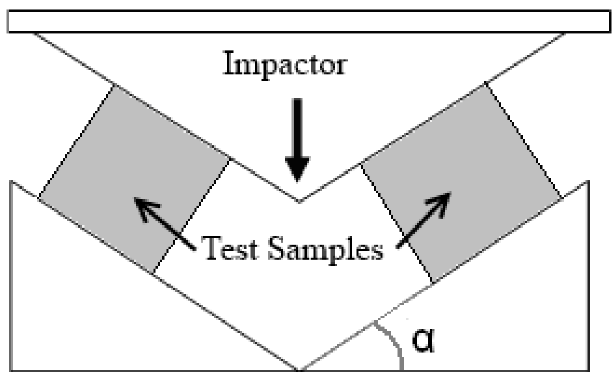
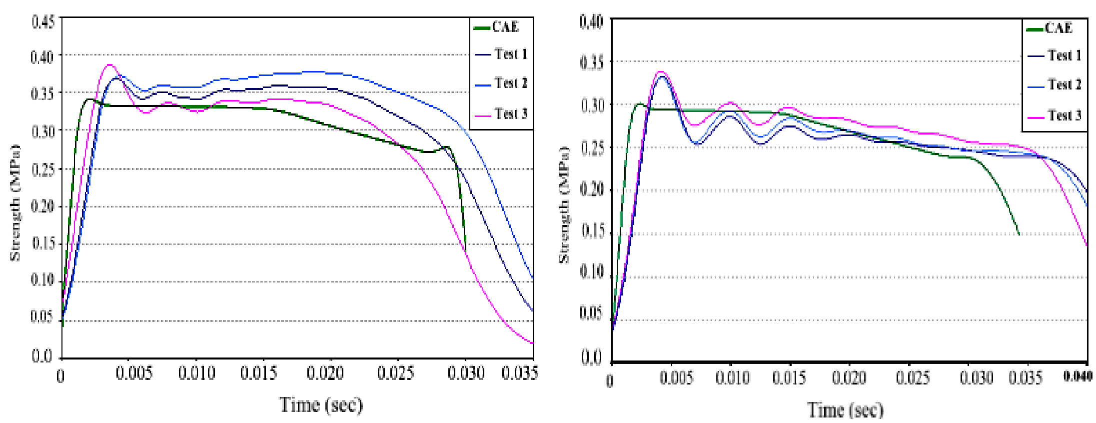


Figure 3. Off-Axis crush test arrangement



a) 15° crush test

b) 30° crush test

Graph 3. Numerical results for angled impact tests

3- Full-Scale FE model for AE-MDB

In the FE model for AE-MDB, each block (A-F) was split into a number of segments with pre-defined depth along the strong axis and a mean strength value was assigned to each segment referencing the nominal crush strength at the start and end points of each section. A strain-rate scale factor curve was also defined for the material cards to reflect the dynamic crash effect on the data obtained from quasi-static experiments. The Arup-Adhesive (Mat 169) material card was also 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. To coordinate the solid element interfaces in a controlled manner during the crash simulation, Null material shell elements were supplied through solid layers in main cores and bumper part. Figure 4 shows the created FE model for AE-MDB.

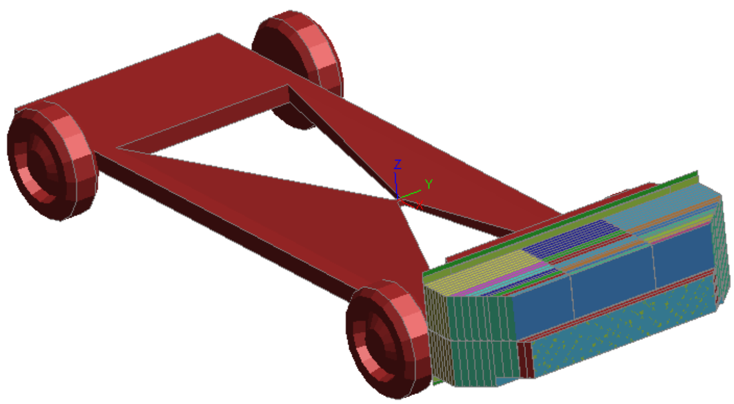


Figure 4. AE-MDB FE model

4- Full-Scale Barrier Tests and FE Results

To evaluate the accuracy of the model, the dynamic analysis was based on two experimental test setups. Flat-Wall test represented the performance of AE-MDB barrier against the load-cell wall. The barrier was mounted on a mobile trolley and tested at 35 Km/h speed. In the Offset-Pole test, AE-MDB barrier was subjected to an asymmetric crash condition with a rigid vertical pole while the test speed was set to20 Km/h (Figure 5). The overall mass of barrier and trolley was1500 kg in tests and data were collected from both load-cells and accelerometers on the COG of the trolley.

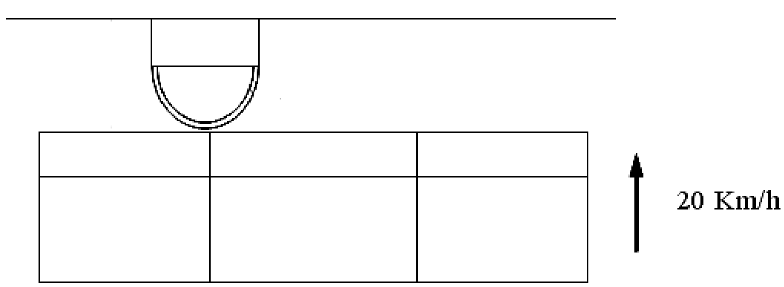


Figure 5. Offset-Pole test arrangement

Figure 6 and figure 7 show the comparison between CAE and experimental results for Flat-Wall and Offset-Pole test cases respectively. The deformed structures and relevant numerical data (Force vs. Time) are shown in the.

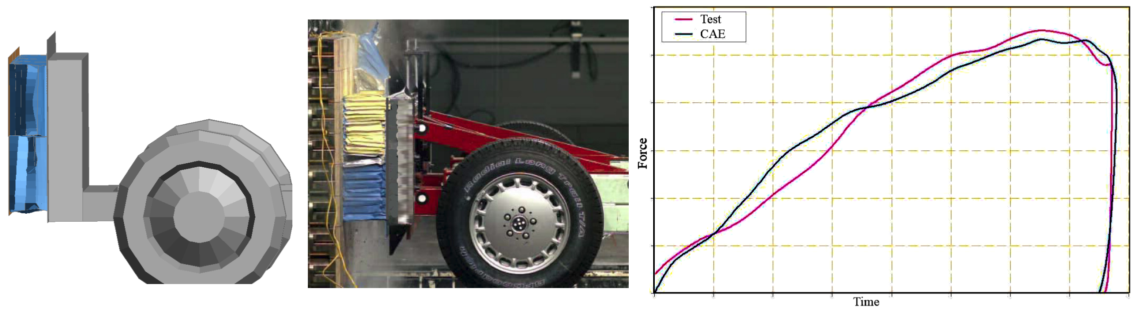


Figure 6. Load-Cell test and FE model

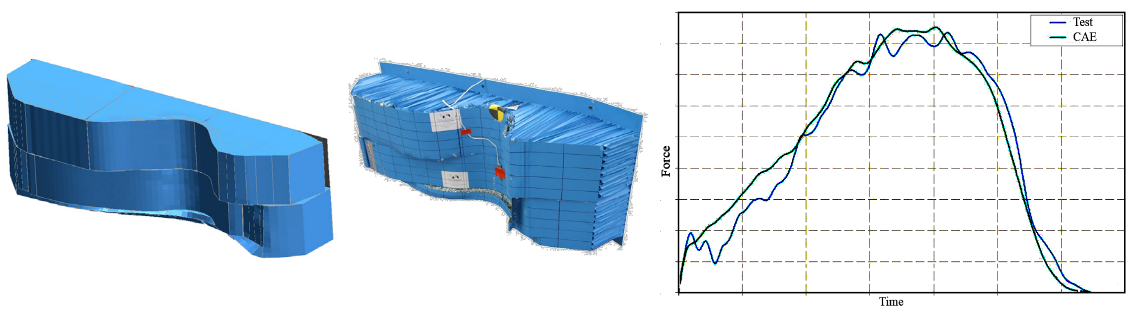


Figure 7. Offset-Pole test and FE model

According to the numerical data graphs, the model shows marginally lower energy absorption rate at the beginning of the impact simulation. This is however negligible and would fall well within a barrier design corridor. The model has precisely represented the collision time compared to the experiments and the numerical data have been correlated well in both test cases. The model has generated a very close deformed pattern while analysed against blockades. In both simulation cases, the crushed area and the trolley's travel distance appear the same in the FE model and the uncrushed honeycomb volume was similar to the physical barrier. In Pole-Test, few separations were observed between honeycomb blocks and the ventilation-support frame of which was well presented in CAE as can be seen in figure 7. Using Null elements between solid layers has had positive effects on controlling the internal interfaces and improved the structural behaviour under local shear applications.

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5- Conclusions

The analysis of the data for AE-MDB v3.9 shows a precise numerical and visual correlation between FE model and the experimental information for both loading conditions. The terminology to establish the material characteristics for MAT 126 material has proven to be effective and consistent with the previous research results. The aluminium honeycomb with differentiated crush strength has successfully been modeled and implemented in the AE-MDB. The supplemental stiffening curves have enhanced the process of the converting the static data for dynamic test conditions while Null shell elements with a reasonable thickness within solid layers have improved the control of the contact between elements in different parts.

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