Finite element modelling and validation of the honeycombs for automobile crash MDB and ODB

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1   Introduction

Honeycomb materials are widely used in automotive crash tests. Typically, it is the main components of the ODB (Offset Deformable Barrier) and MDB (Mobile Deformable Barrier) stipulated in ECE Regulation No.94 and No.95 on automotive crash test. These two kinds of honeycombs or barriers are also adopted by Chinese regulations. The accuracy and efficiency are most important for the CAE analysis of automotive crash simulation. In the earlier the solid elements is mainly employed for honeycomb modelling due to the limitation of computer calculation. The challenge of the solid element modelling is to overcome the hourglass energy, computational stability and local deformation simulation, etc. Recently, with the rapid improvement in computer hardwires, the shell elements are more and more used for modelling the honeycomb [1][2][3]. The shell model for honeycomb has some advantages such as high computational stability, lower hourglass energy and good simulation for detailed local deformation. The shell models of honeycomb can be found from the LSTC Inc. and Wang [3]. In China, the majorities of auto manufacturers still use the solid model of honeycomb from overseas commercial models such as ARUP and ESI honeycomb models. The shell model of honeycomb hasn't yet been widely used because it is in grow-up stage and needs more validations for its accuracy. Meanwhile, some data or parameters in these commercial models is invisible and cannot be handled. Furthermore, some problems were found in the actual CAE applications, such as too strong glue, excessively hard character of the whole honeycomb and abnormal energy, and so on. On the other hand, many auto manufacturers still insist on developing own honeycomb models so that they can grasp the whole analysis simulation.

Based on the experimental data and other literatures, this paper presents the FE models of ECE ODB and MDB developed by LS-DYNA®. By means of whole vehicle crash validations, these two models can give a good accuracy and computation stability. All the codes of these models will be opened to the public so that it will be helpful for auto engineers to comprehend the details of the honeycomb model and to improve the models.

2   ODB and MDB honeycomb modeling

In frontal crash test the ODB honeycomb is subjected from more severe deformations: extremely compression ratio, drastic shear, tear of aluminium foil, tear of the facing or cladding sheet, failure of glue, peeling of aluminium foil, etc. Furthermore, the ODB honeycomb has a smaller size than MDB. In view of the above, the shell element is more suitable for modelling the ODB honeycomb.

In view of larger size for the MDB honeycomb, the shell element model will lead to an enormous scale, so the solid elements are usually employed to establish the MDB honeycomb model. In the side impact test according to ECE R95 compression and collapse are the main deformation mode for the MDB honeycomb. The deformations such as shear, tear and failure are not so severe than ODB honeycomb. Therefore, the solid element model will greatly improve the computational efficiency with good accuracy. The MDB honeycomb model is built by using solid elements in this paper.

2.1   Modeling of MDB honeycomb

MDB honeycomb consists of six blocks, in each block the aluminium foils have a tapered thickness from the rear end to the front face. This leads to the harder rear end and softer front end. Multi-layers discretization is a feasible means to deal with the tapered thickness. The brick elements with size of 25mm are used to establish the model. Every face of the brick element is covered by a Null element

with thickness of 0.5mm in order to avoid negative volume and assure the effect of self-contact algorithm. There's a gap of 2mm between each block in order to avoid violent friction which can lead to abnormal deformations. The MDB model established in this paper has a large calculation time step of 1.5μs, with 134151 elements and 60793 nodes. The section force for each block is output by SECFORC keyword.

In this model the aluminium foil, glue and the air in the hexagon holes for each block are totally considered as a new anisotropic foam material, whose density and elastic modular should be different from aluminium. The MAT126 with type 0 in LS-DYNA® software is selected for this new material of the bricks element. For this new material the Strain is calculated by volume variation while the stress is the load divided by whole section area. For type 0 of element formulation, the components of stress tensor are uncoupled each other. The uncompressed elastic modulars (E_{aau}~E_{ccu}, G_{abu}~G_{cau}) are used instead of elastic modular after compacted (E). Note that the plastic compression and collapse are the most important deformation modes other than elastic deformation for MDB honeycomb in vehicle side impact. The normal stress-strain curves are presented by LCA, LCB and LCC in LS-DYNA®. For each block the strength curve along T-direction (LCA) is discretized based on quasi-static compression test data [4]. The strength along W-direction is nearly equal to the strength along L-direction, which is about 1/10~1/50 of the strength along T-direction [4]. The W-T shear strength is about 1/5~1/4 of the strength along T-direction with a failure strain of 0.6. Hourglass control with type 2 is imposed to all solid elements in order to control the hourglass energy. The glue between the aluminium foil and facing sheet is simulated by many beam elements. The lateral shrink of the facing sheet from blocks during the impact can be simulated by failure of beam elements and shear deformation of the brick element. Dynamic effects are achieved by appropriate value of strain rate. Herein the strain rate LCSR is set 1.25.

The modelling for other parts of MDB is simple: the trolley can be treated as a rigid frame; the tire can be simulated by simple airbag model. The mass and centre of gravity must meet the requirement of ECE R95 via adjusting the mass distribution. Accelerometer is used to output the acceleration of the trolley.

2.2 Modeling of ODB honeycomb

Actually, shell element model is the original choice for honeycomb at the earliest, but this may produce a very large scale of model so as to it can't be accepted. Even in the present with the unprecedented high performance computer, it's necessary to reduce the scale of shell model for honeycomb. Usually the sizes of honey-comb holes need to be enlarged with the increase of shell thickness for the aluminium foil. Therefore, the total number of elements of the whole model may be not more than 300,000. Take an example, the shell model of ODB honeycomb released by ARUP in 2010 has totally 286,653 deformable elements with the honeycomb hole of 52mm[5].

In this paper the sizes of honeycomb holes are also been enlarged: the length of side of hexagon in main block is enlarged from 11mm to 40mm, while length of side in the bumper from 3.7mm to 20mm. The final model has 171,633 nodes and 178,563 elements with time step of 1.1μs. The stiffness becomes softer due to the increased hexagon hole so that it cannot meet the requirement of ECE R94. To solve this problem, one needs to increase the shell thickness of the aluminium foil and decrease the yield strength of the material. The MAT24 of LS-DYNA® is adopted for the materials of aluminium foil, facing sheets, cladding sheet. The Contact with keywords "Contact_automatic_surface_to_surface_tiebreak" is used for simulating the glue for the facing sheet to the bumper foil, the bumper foil to the cladding sheet, the cladding sheet to main block, and the main block to the backing sheet. The connection between the cladding sheet and backing sheet is defined by a keyword "Constrained_extra_nodes", while the connection between backing sheet and the fixed wall is defined by "Constrained_rigid_bodies". The impact force to the ODB is output via cross section force by SECFORC keyword. The mode is shown in Fig.1.
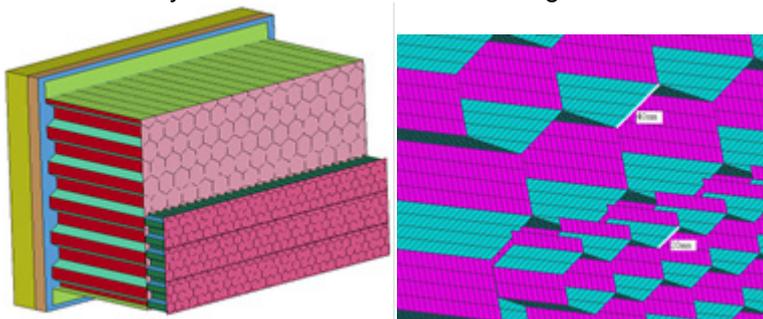

Fig. 1: Shell element model of ODB honeycomb of this paper

3   Model validations

The requirement in ECE Regulations must be met for the honeycomb models. Besides, the model would better meet other requirements from the recommended dynamic test by EEVC (European Enhanced Vehicle-safety Committee) as possible. The follows give the introduction of the model validation results.

3.1   Validation with ECE Regulations requirements

According to ECE R94 and R95, there's only static requirement for the ODB honeycomb, while the MDB honeycomb must meet the requirements from both static compression and dynamic impact to a rigid wall with a speed of 35km/h. The models presented in this paper can meet all requirements from ECE R94 and R95, with a part of results shown in Fig.2 - Fig.4.
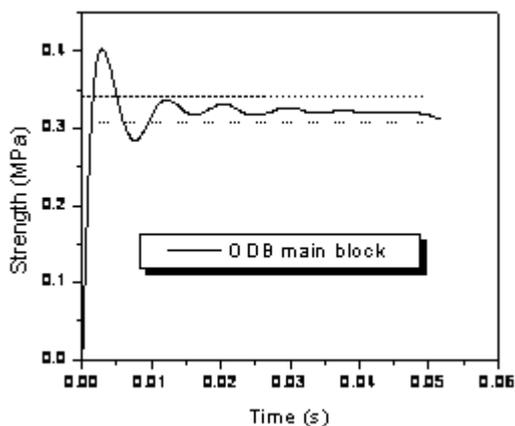
Fig. 2: Static strength of ODB main block Figure 3.   *Fig. 3: Static strength of MDB (Block 5 & 6)*
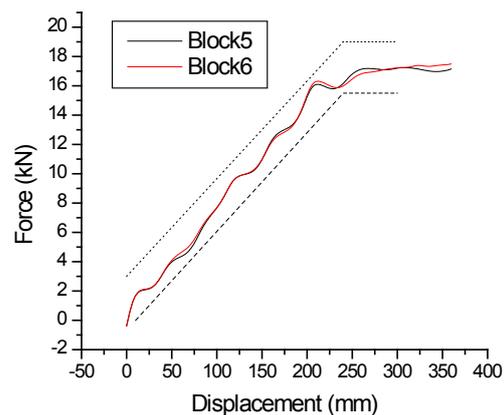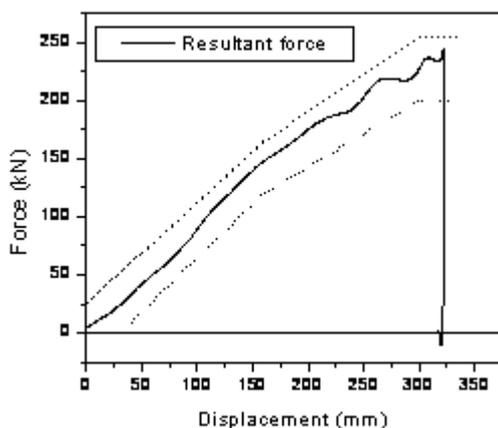
Fig. 4: Resultant force of MDB in dynamic test of ECE R95

3.2   Validation with Other requirements

In general, The ECE regulations have only simple requirements for the MDB honeycomb. In order to extensively check the differences among several honey-comb manufacturers, EEVC WG 13 recommends several dynamic tests, typically such as impact with offset pole and rigid sill loading test. Because EEVC doesn't give more tests for the ODB, some tests results from literatures are used for validation herein.

3.2.1 MDB validation with EEVC recommended tests

(1) Offset pole impact
The frontal impact test to a rigid offset pole with 20km/h can be used to assess the extent to which the barrier face represents that of the front of a real vehicle when impacting a narrow obstacle generating a concentrated force. The offset pole can test the ability of the barrier face to transfer impact forces

from one part of the barrier to an adjacent part in a similar manner to real vehicles and also test its sensitivity to location of the stiff structure.

The results of the MDB model of this paper (called SMVIC model for short) has good agreements with EEVC test. As shown in Fig. 5 and Fig. 6, the SMVIC model exhibits a little harder than the real MDB honeycomb.
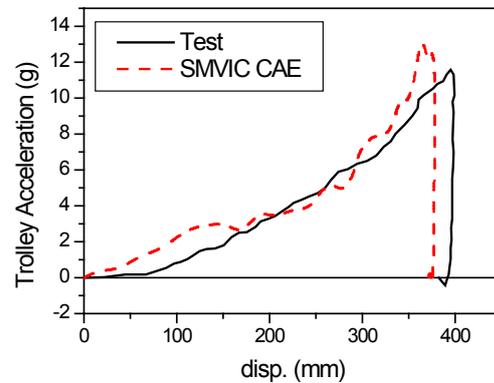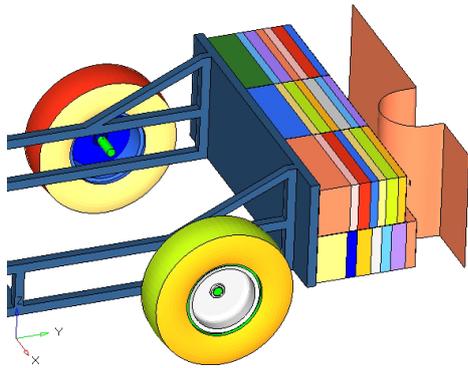

Fig. 5: FE model of MDB with an offset pole   Fig. 6: Acceleration of MDB impacted with offset pole

(2) Rigid Sill Loading Wall test (RSL)

The RSL test simulates an impact into a rigid vehicle sill with a speed of 35km/h. The honeycomb part is inverted on the mobile trolley so that the bumper section of the barrier face impacts the simulated sill and is prevented from riding over the sill during the impact. The result of the SMVIC model agrees very well with the two tests of EEVC (see Fig.7). More detail results are given in Ref. [6].
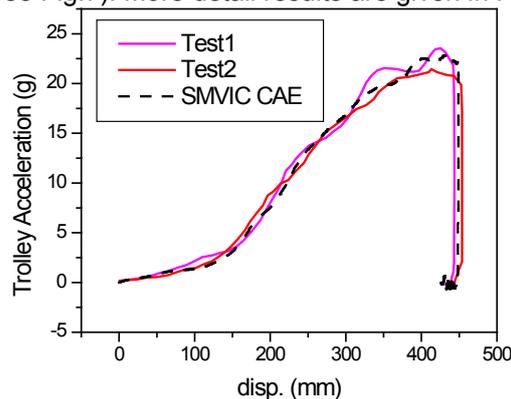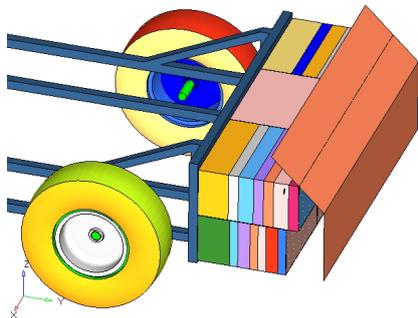

Fig. 7: Acceleration of MDB (Rigid sill loading test)

3.2.2 ODB validation with component tests

Some impact tests by a bar or wall were conducted by Cellbond Inc. These tests are much more rigorous than the regulation test conditions and the results have more uncertainty. Even for the same impact conditions, two tests may lead to quite different results. Ref. [5] has pointed out that the CAE model of the barrier is also sensitive to where and how the main cladding starts to tear, and as such variations in the model setup, LS-DYNA® version or analysis machine can result in a change in how the cladding tears and hence the behaviour of the model post failure. These tests will be used for the validation of the model of this paper, including the rigid wall impact, the half wall offset impact, the low horizontal bar impact, the high horizontal bar impact and the vertical bar impact [5]. The comparation with the test data is shown in Fig.8 ~ Fig. 11, in which the legend "solid model" represents the results from another honeycomb model by solid element method. On the whole, the ODB shell model presented by this paper has good coincidence with the test data. The result analysis is omitted herein owing to the space limitations. More detailed results and validation can be found in Ref. [7].
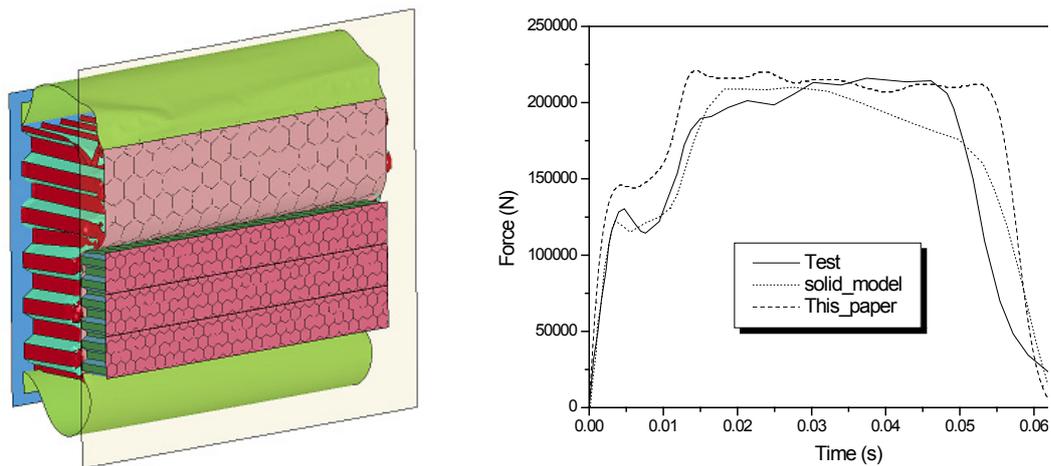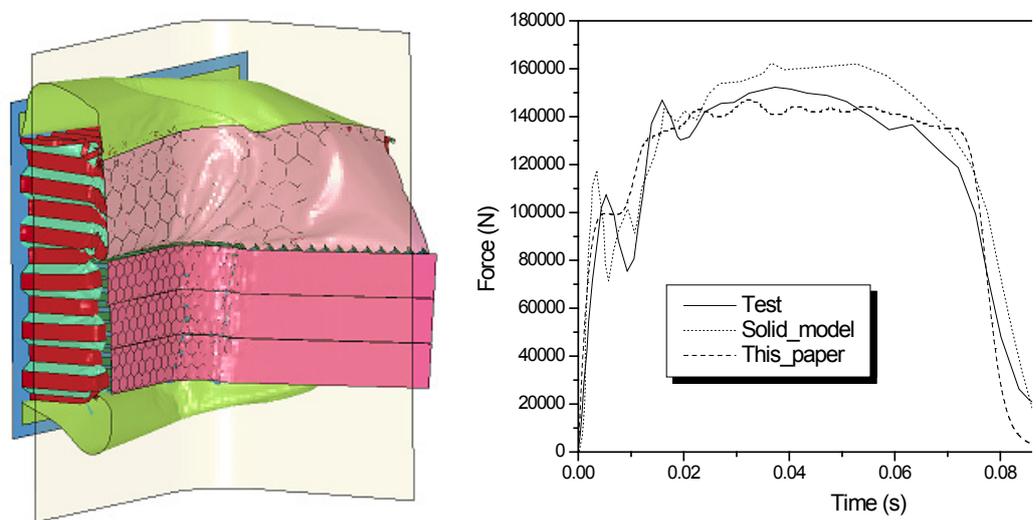
Fig. 8: Results of ODB impacted with flat wall

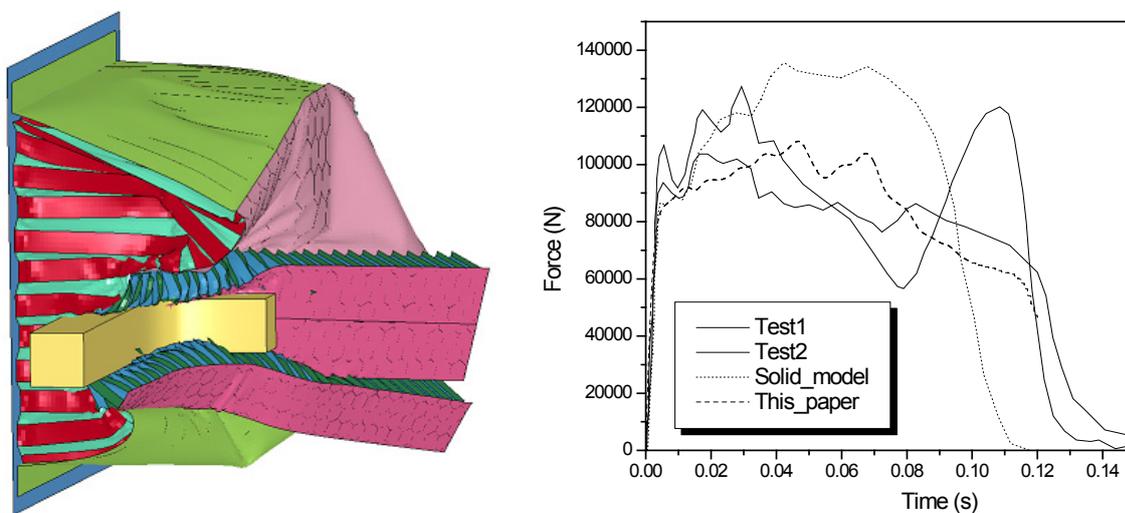
Fig. 9: Result of ODB impacted with half wall

Fig. 10: Result of ODB impacted with lower bar
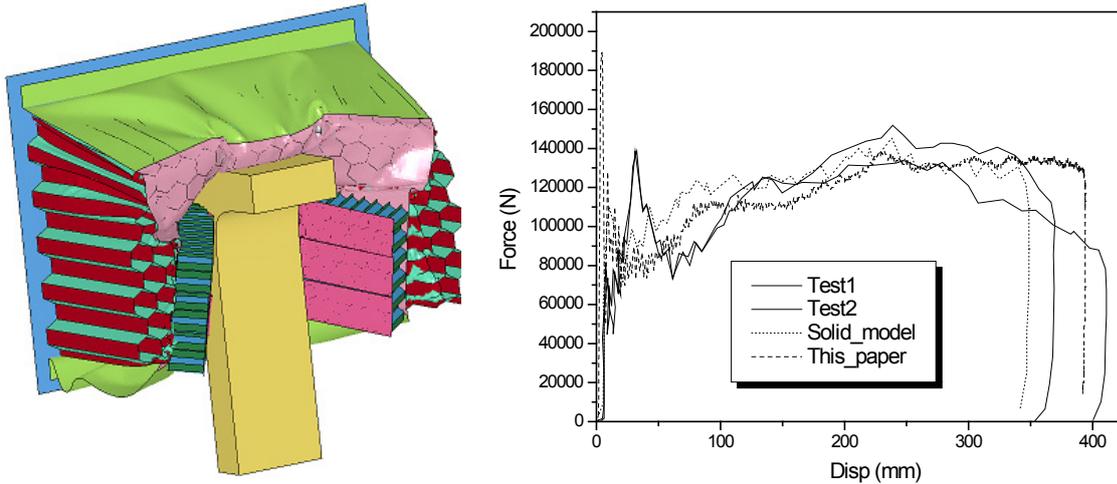
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Fig. 11: Result of ODB impacted with vertical bar

3.3 Validation with vehicle crash

3.3.1 ODB honeycomb

(1) The frontal crash test was conducted by a mini-bus according to ECE R94 with a speed of 56km/h. Due to the large mass (about 2000kg) of vehicle, the ODB honeycomb suffered severe compression, shear and tear deformations. The results of left B-pillar acceleration are given in Fig. 12, in which the legend "solid model" represents the results from another honeycomb model by solid element method. The two models can get close results that mainly agree with the test data.
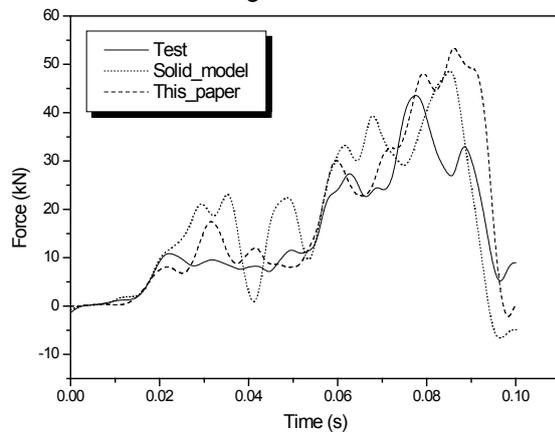

Fig. 12: B-pillar Acceleration of a minibus in ODB frontal crash

(2) Another validation is carried out by comparing the results of this paper with that of ARUP commercial model. Fig. 13 shows the accordant results of left B-pillar acceleration of a passenger car during the frontal offset impact simulation according to ECE R94.
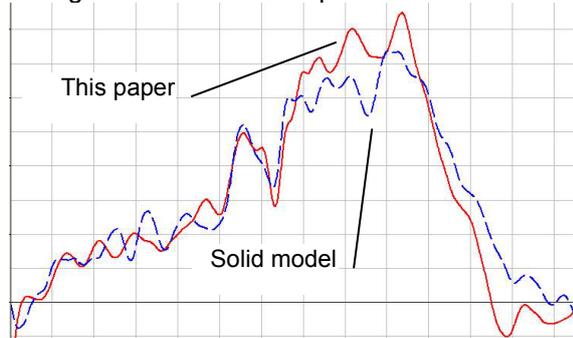

Fig. 13: B-pillar Acceleration of a car in ODB frontal crash

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3.3.2 MDB honeycomb

A new passenger car is used for the validation of the MDB honeycomb model. However, the acceleration data of the mobile trolley is lost during the side impact test according to ECE R95. The results for trolley acceleration and the intrusion of B-pillar are given in Fig.14 and Fig. 15, in which the legend "SMVIC", "B" and "LSTC" present the result from the model of this paper, another solid commercial model and LSTC model, respectively. It can be seen that all the results are consistent.
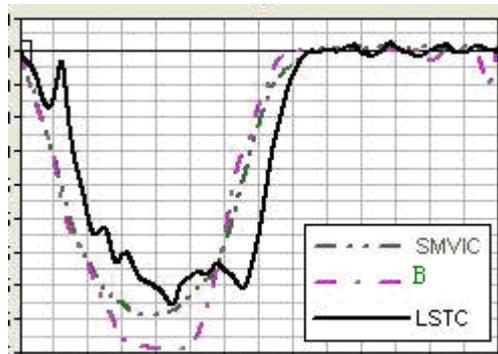

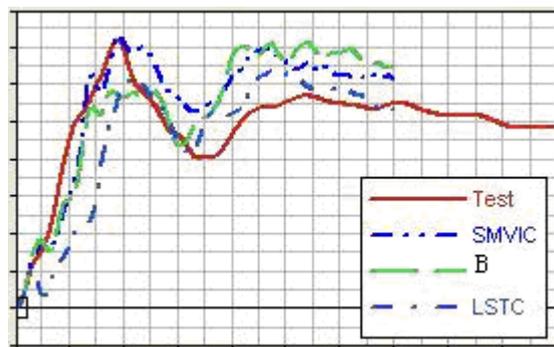*Fig. 14: Acceleration of trolley in side impact with a car*

Fig. 15: Intrusion of B-pillar in side impact

4   Summary

The CAE models of the ODB and MDB honeycomb are developed in this paper. The MDB honeycomb is modelled by using solid elements which has a good accuracy and efficiency while the shell elements are employed to build the ODB honeycomb model. Both the ODB and MDB models can meet the requirements of ECE regulations and have good agreement with the EEVC recommended tests and other more rigorous component tests struck by half wall, vertical and horizontal bar. By means of whole vehicle crash validations, these two models of this paper are shown a good accuracy and computation stability. All the codes of these models will be opened to the public so that it will be helpful for auto engineers to comprehend the details of the honeycomb model and to improve the models.

5   Literature

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