Failure Modes Analysis in the Crash Barrier Simulation

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Abstract

The technology of FEA modelling is expanding rapidly in the field of automotive safety analysis. From the pre/post-processing for the material impact to the mathematical equations in the solver the non-linear analysis becomes a vital part of the simulation. In this paper we trace the development of experimental data validated-analysis method for the Cellbond honeycomb barrier model by using **LS-Dyna** software.
The utilization of the database from IIHS and Advanced-MDB cores in the estimation of solid material parameters enables our simulation well framed into the impact criterion corridors. Over the past 10 years in Cellbond Ltd, at least three general categories of experimental-analysis methods can be identified in the failure modes classification: (1) Forced-Normal Mode Tests, (2) Dynamic Frequency-Response Filtration and (3) Mathematical Estimate against Theory.
FEA impact-analysis method for each of these categories can be incorporated as multiple-input concept in one way or another. Historically, the failure modes characteristics of structural mechanical systems have been estimated by techniques that fall into either the first or second category. The forced-normal mode tests method has always been included in the repeated single inputs concept while the Dynamic Frequency-Response Filtration method, until recently, only involved the application of multiple-input.
This paper presents a generalised FEA-modes-analysis method with emphasis on the including the refinements of the previous methods. The FEA-modes-analysis method, that fall into the last two categories are composite approaches that utilize the static load-curve estimation algorithms based upon structural models and include multiple-input concepts. The current FEA developments in the areas of dynamic simulation are encouraging.

Introduction

Objectives
Identify the Crash Modes in Impacted Barriers
Honeycomb Model
IIHS & A-MDB Barrier Simulation
Non-Linear Analysis
Conclusions to the Shell and Solid Element Modelling

1. Identify the Crashed Modes in the Impacted Barriers

The modelling is based on the laboratory impact testing. First of all we need to identify the crash (including failure) modes with nonlinear analysis. Then, we carry out FEA simulation and assemble to the solid model.

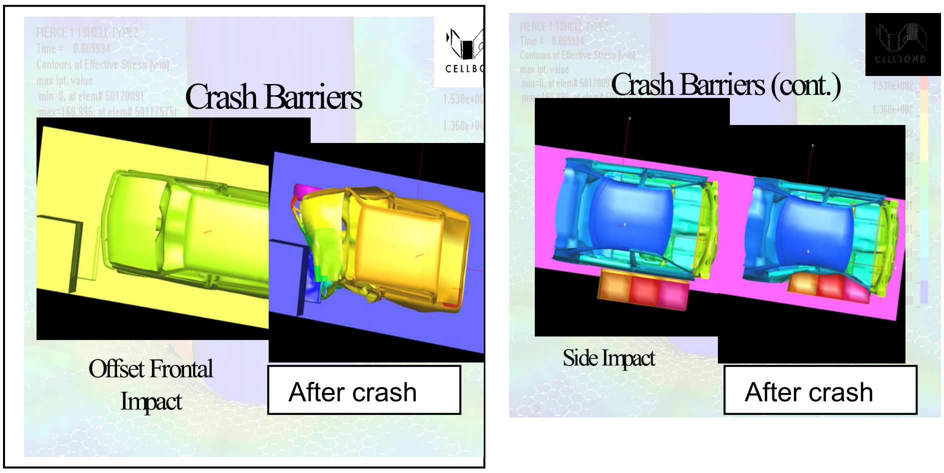


Figure 1. The laboratory regulated impact: before and after crash.

The laboratory testing configuration is for the off-set frontal and side impact experiments; which is our physical back-ground of the simulation.

2. Honeycomb Model

In normal compression simulation, the honeycomb model agrees with the test (EEVC WG13, 2001) of advanced 2000. For the regulated impact (mass 550kg, v=15.7m/s) the dynamic simulation is comparable with the test (i.e. yields dynamic force 225 kN in 0.3m crush depth). The prediction is well framed by the static corridors. There are no angle shear slip and tearing modes dominating the crush in the honeycomb model.

When the offset frontal and side impacts are analysed, we find the failure modes become dominant. This increases difficulties for our honeycomb modelling. By using FEA nonlinear analysis we carried out two phases of study known as: microscopic simulation and macroscopic modelling.

In the dynamic test analysis, signal filtration is an important step during the two phases at modelling. The repeated tests give us large amount of information to obtain the theoretically sound mathematic prediction, which also confirm the test results for the honeycomb model.

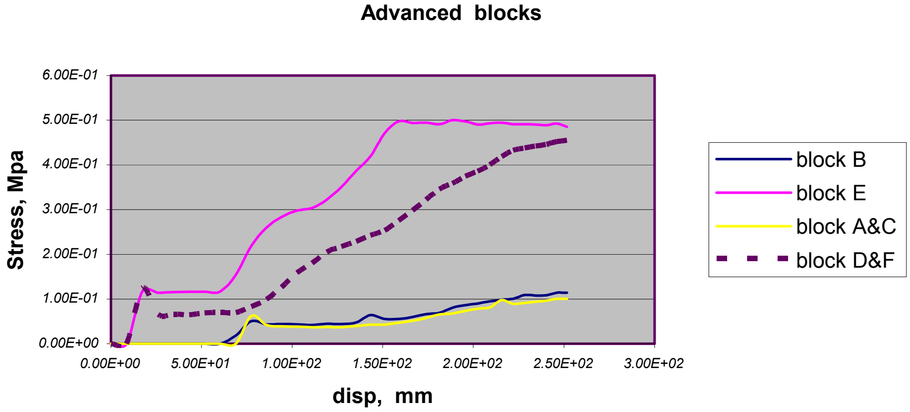
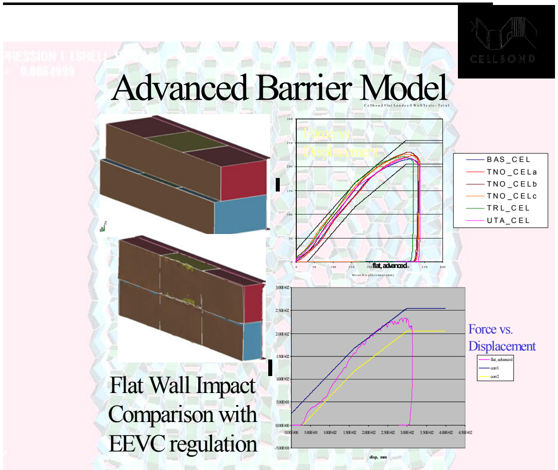


Figure 2. The load-curve for the blocks of the advanced core.

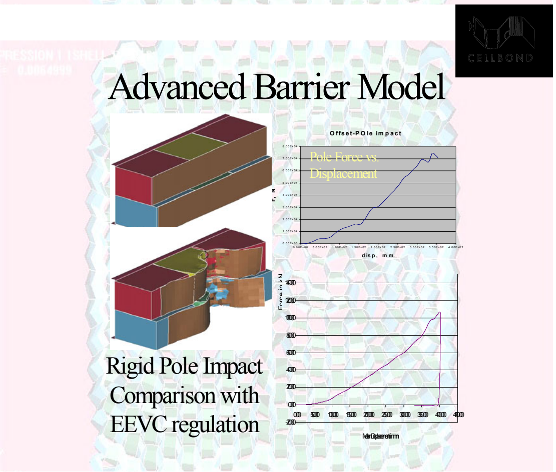
The advanced cores, with corridors for each of its blocks, have been tested by EEVC, WG13. In our recent FEA simulation, the force-displacement static corridors have been converted into stress-displacement (then strain) load-curves for the LS-Dyna simulation. The simulation with solid element type 0 and modified honeycomb material card yield consistent agreement with the testing result (confirms the static calculation in the energy absorption for the advanced blocks).

3. IIHS and AE-MDB Barrier Simulation



Advanced Barrier Model

Flat Wall Impact Comparison with EEVC regulation



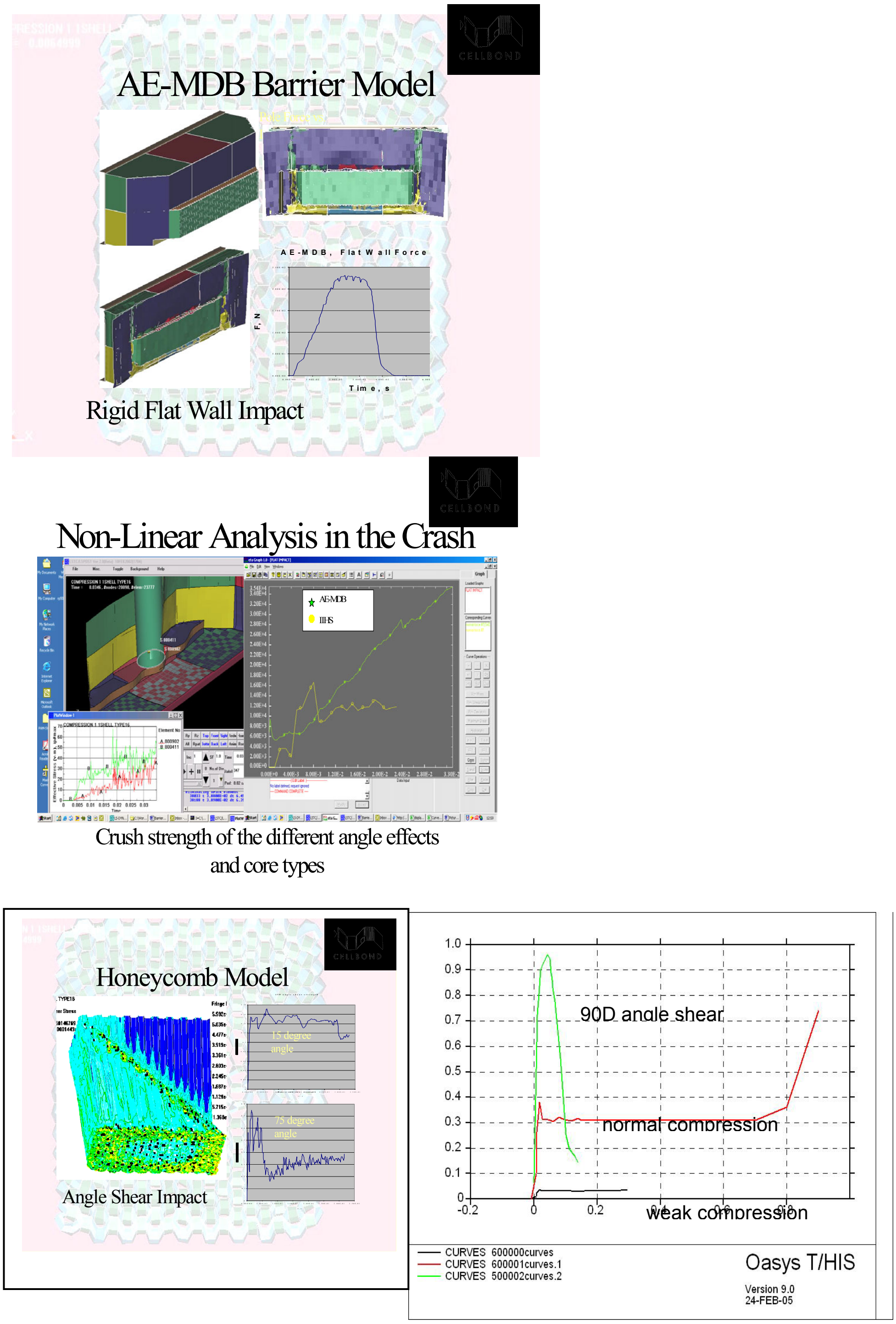
Advanced Barrier Model

Rigid Pole Impact Comparison with EEVC regulation

Figure 3. The regulated impact: 550kg mass impactor; v=15.7m/s; yields force F= 225.4 kN.

A good comparison is obtained for the rigid wall frontal impact, i.e. the advanced 2000 test and our FEA simulation (up left); and the advanced 2000 rigid pole impact test and our FEA simulation (up right). The IIHS (down left) and AE-MDB (down right) for the rigid wall and rigid pole impact predictions need further investigation, as the angle shear, piercing and tearing failure modes play important roles.

4. Nonlinear Analysis



AE-MDB Barrier Model

Rigid Flat Wall Impact

Non-Linear Analysis in the Crash

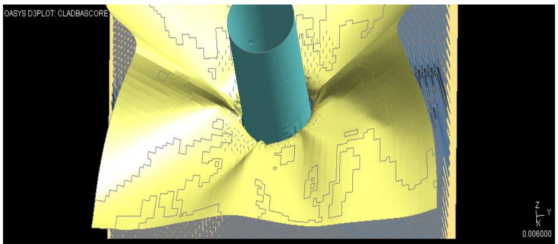
Crush strength of the different angle effects and core types

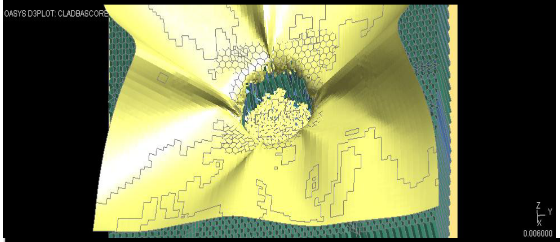
Honeycomb Model

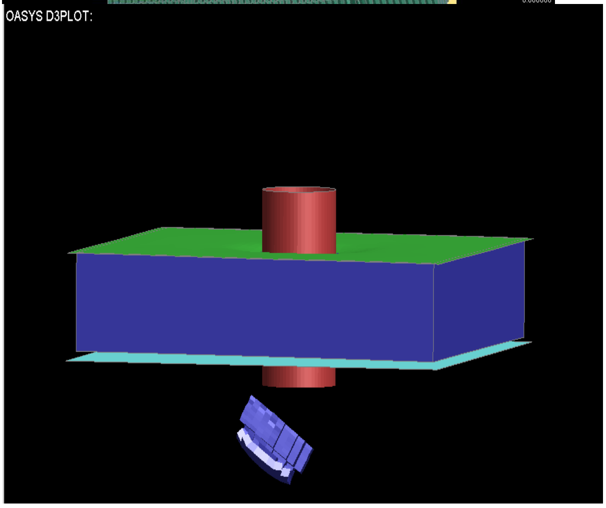
Angle Shear Impact

Figure 4. The microscopic analysis for the angle shear and pierce/tearing effects.

When the angle shear, pierce/tearing modes mixed into the crash test simulation, the solid element modelling do not agree naturally with the experiments. To solve the problem we study the shell element model to explore the microscopic failure modes. The piercing and angle shear models are not consistent in both the rigid wall and pole impact modelling (up left and right).This is the motivation of our study for the angle shear simulation with systematic investigation for angles (i.e. 15, 30, 45, 60, 75, 90 degrees). We discovered yield surfaces in shell element model, and be able to extrapolate the load-curve for 90 degree angle from lower degree angle shear results (down left and right). The load-curves presented here, known as: normal compression which is strong direction of the core; the weak compression which is the weak side direction of the core; and the 90D angle shear which is pure shear, are most important part of the solid element model formation. Numerically the tensile and densification stress locking are applied to ensure the positive definite volume. With this two phase study the stability of the solid element model for the honeycomb is guaranteed.







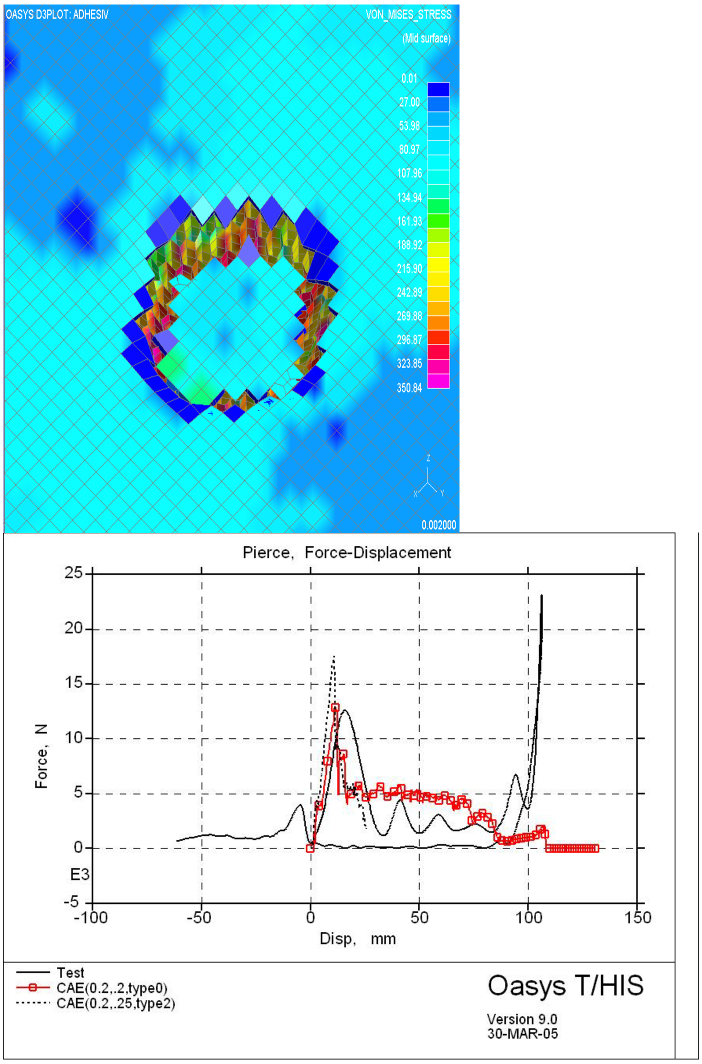
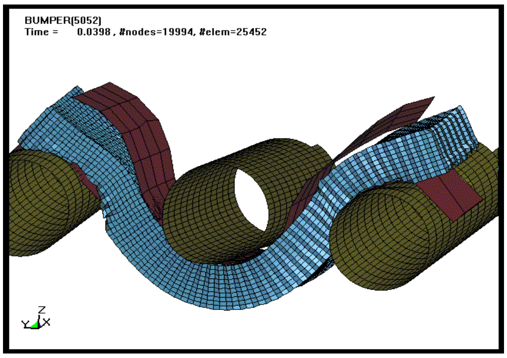


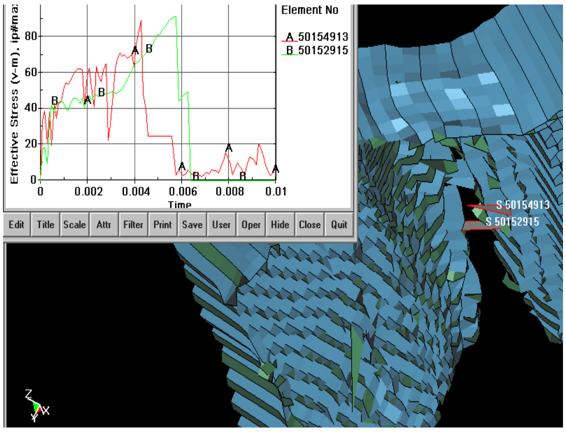
Figure 5. The 2 phases transition in piercing model. The solid element size=10mm; shell element size=5mm; 10 shells within 1 solid volume therefore 10 times slower (impactor mass 82kg, V=3.9m/s).

There are always the efforts to balance the computing cost for large number of element with fine mesh size and the quality of the simulation in comparison with the test. To analyse the gap in the micro & macro-models we investigated in detail by use of MPP/MPI 4 CPU clusters (up left & right). We find that the accurate adjustment of the shear elimination for both the modified-honeycomb for solid element and modified-piecewise-linear-plasticity for shell element material cards is also the key point for the quality of the refined simulation.

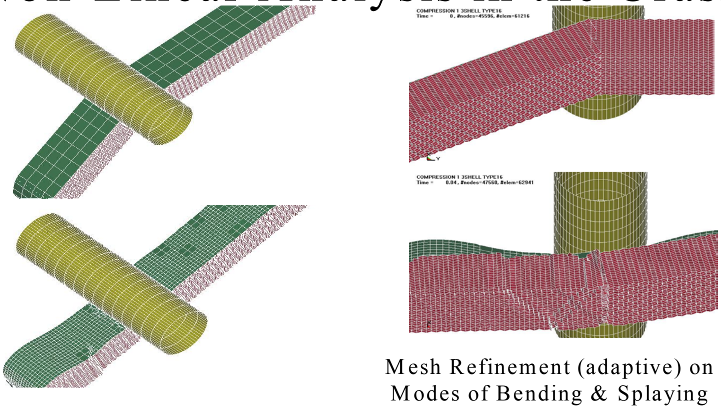
A comparison for the solid element type 0 with engineering strain and type 2 with logarithmic strain are given here. Generally speaking, type 0 performs better with 1 point integration scheme (down right). The comparison of the shell element model (up left) and solid element model (up right) is also given. The solid element size=10mm; shell element size=5mm; 10 shells are within 1 solid volume therefore approximately 10 times slower (down left). Therefore we recommend the solid element model for the generalised macroscopic model behaviour.



Modes of Bending Moment & Slip



Non-Linear Analysis in the Crash



Mesh Refinement (adaptive) on Modes of Bending & Splaying

Figure 6. The simulation on the modes of bending and twisting.

Other important failure modes, i.e. bending (up left) and twist/tearing (up right) are also studied with careful analysis. The adaptive mesh performs well in studying the splaying modes during the bumper bending on the barrier corner (down left and right). Therefore the microscopic nonlinear analysis gives us very realistic view in understanding the phase up-grading for the macroscopic modelling process. These microscopic noisy signals have been filtered to supply useful information for the phase transition and macroscopic solid element model formation.

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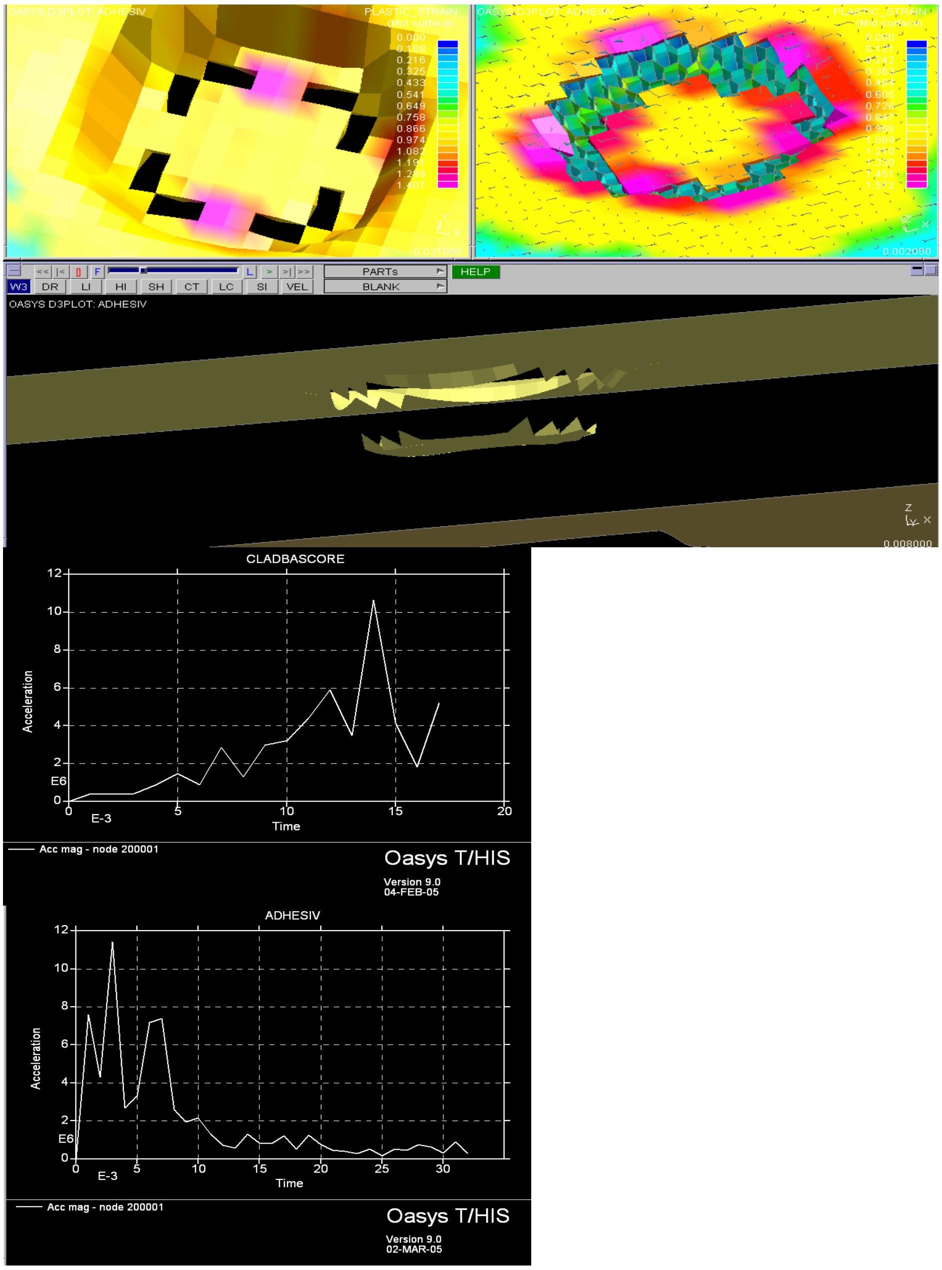

Figure 7. The adhesive effects in honeycomb modelling.

The adhesive effect has been studied in simulation as well. The pierce with cladding performs in a very different way if we switch on or off the adhesive in modelling. The wrong elimination strain of adhesive (up & down left); and right elimination strain of adhesive material (up & down right) yield different piecing stress peak as in the curves (down left & right) respectively. The centre figure is the cladding pierce simulation.

5. Summary and Conclusion

The solid element model represents the generalized model strength and crush behaviour with much less computing cost. A good comparison with test is obtained.

The shell element analysis is performed when the detailed deformation and non-linear properties are needed with the cost of massive computing (i.e. the cubic core with 50K elements).

The macroscopic solid model performs well for the normal impact with regular behaviour; the microscopic shell element slip/tearing behaviour can supply detailed understanding of some irregular behaviour in the dynamic impact.

Acknowledgement

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