Alternative Models of the Offset and Side Impact Deformable Barriers

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Abstract

The deformable barriers consist mainly of honeycomb blocks with highly anisotropic behaviour. These parts are made from several layers with aluminium foil that is glued and stretched to form the honeycomb structure. Simple compression tests show high stiffness and strength when the cell structure is folded while both stiffness and strength are significantly lower when the deformation mode is mainly bending of the thin foil. Remember that the typical deformation mode involve also transverse displacement of barrier parts, and when the honeycomb structure is folded this may be seen as the interaction between local and global buckling.

Therefore, shell elements are used to model the honeycomb structure, and alternative models of the offset and the side impact deformable barriers are made. Note that scaling is used extensively to limit the number of elements and thereby the computational time that is required. These models with about 30 000 shell elements seem able to predict the global response of the deformable barriers, and they may be easily refined to represent more local behaviour as well.

Keywords:
Energy absorption, aluminium honeycomb, anisotropic behaviour, fracture, shell elements and MAT_024

Introduction

Numerical simulations are extensively used to improve automotive safety, and it is therefore crucial to properly represent the properties of the deformable barriers. Remember that the main parts of these barriers are made of honeycomb, and in a frontal offset collision or a side impact test this material is compressed not just along the main axis, but also in the oblique direction. For aluminium honeycomb the compression property along its strong axis is well known, while less work has been carried out to investigate the properties connected to other deformation modes. Kojima et al. [1] have performed compression tests on aluminium honeycomb blocks that were cut with varying orientation relative to the strong axis. As expected, the zero-degree test shows the highest compressive strength, while the test pieces cut at angles of 60 degrees or more, show less than one tenth of the zero-degree reference. Thus, in order to represent the variation in compressive strength, a new yielding function was incorporated into MAT_126 [1].

Also the present paper focus on the compression properties of honeycomb, but the anisotropic behaviour is seen as interaction between local and global buckling when folding the cell structure. This means that a simple material model seems sufficient and shell elements are used to model the geometry. The computational resource is limited, and therefore a cell structure with small cells should not be modelled with a large number of elements forming the cross section of each cell. Thus, the main objective of the present study is to find an “optimal” scaling where the cell size as well as the number of elements to represent each cell is chosen to give the "best" representation of the deformable barrier related to the computational time required. Finally, alternative models of the offset and side impact deformable barriers are made, fracture in the barriers are evaluated by comparing numerical predictions and tests.

Scaling

Figure 1 illustrates how honeycomb parts can be made from foil. It seems like the angle H is about 90 degrees, and the distance M where two foils are put together is nearly the same for both 0.34 MPa and 1.7 MPa honeycomb. However, the distance L is varying and the width to thickness ratio for this wall is the main parameter that governs the compressive strength.

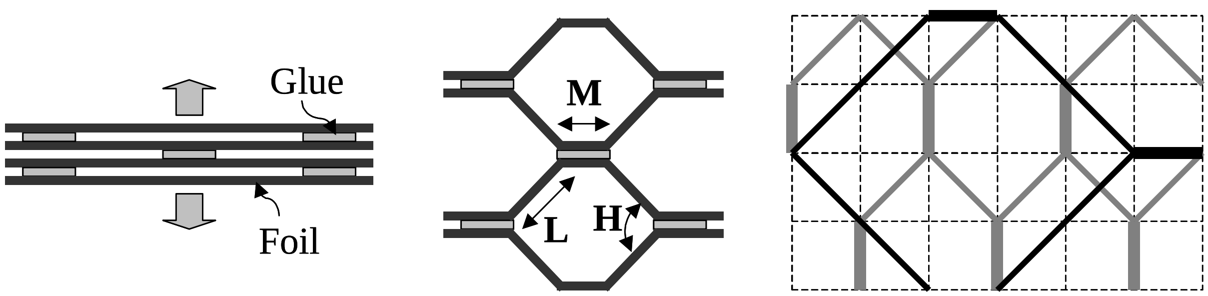
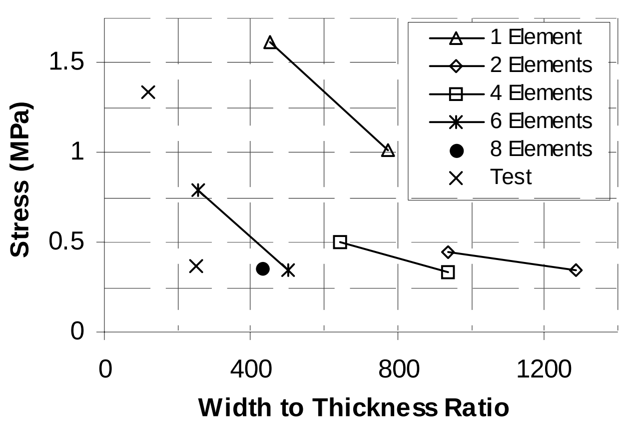


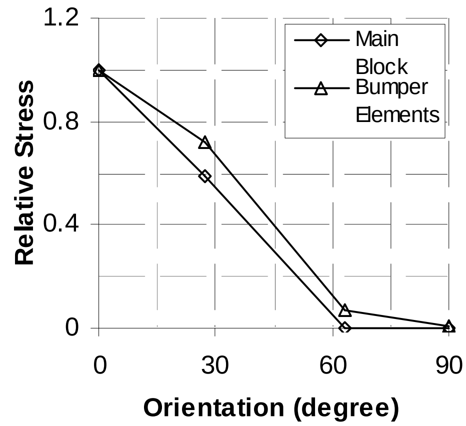
Figure 1. Parameters that define the geometry of the honeycomb cell structure

In the present study, the geometry of the numerical honeycomb representation is defined by four times six squares. This area may be seen as 24 shell elements in the cladding sheet, and the shell elements that make the honeycomb main block and the bumper elements may have common nodes, see Figure 1. This allows a simple representation of the adhesive between these parts, and a tied contact that easily introduces relatively large contact forces can be avoided. Note that the present part is scaled and repeated to form the whole barrier.

A numerical study of compression tests on honeycomb pieces that were cut out with angles about 0, 27, 63 and 90 degrees relative to the main axis indicated that even a very coarse shell model seems able to represent the global behaviour of the honeycomb cell structure [2]. But the numerical thickness has to be reduced to achieve the correct compressive stress, and in Figure 2a this is shown as an increasing width to thickness ratio for coarser meshes. Note that for the case with only two elements over the width of each wall the numerical thickness is about one fifth of the real value, and this numerically increased slenderness seems to effectively reduce the stiffness and strength for both the crushing and the bending modes [2]. Figure 2b shows the predicted relative stress at 20 % volumetric strain as a function of cell orientation, and these numerical results corresponds well with the experiments by Kojima et al. [1].



(a) Effect of mesh and width to thickness ratio



(b) Effect of cell orientation

Figure 2. Results from initial simulations to investigate scaling effects [2]

Numerical Models

The barrier models are based on the cell geometry shown in Figure 1, and this patch is scaled and repeated to build the barrier geometries. Note that the base mesh has cells that are enlarged about 5 and 6 times for the main block and bumper elements, respectively. In addition, the width to thickness ratio is increased to predict a reasonable crushing force with 18 mm shell elements. Thus, the numerical thicknesses 0.070 mm and 0.095 mm that represent the main block and bumper elements were chosen in accordance with Figure 2a. For the offset deformable barrier both the main block cladding and the bumper facing sheets are 0.8 mm thick, while the side impact deformable barrier has a 3.2 mm thick aluminium sheet in front, see Figure 3. The numerical simulations were performed using the finite element code LS-DYNA [3] and timestep dt = 1.2 10^{-6} second. The material properties were defined using von Mises yield criterion, and based on the values for yield and ultimate stress [4], some stress-strain curves for aluminium 3003 foil and sheets were assumed, see Table 1.

Table 1. Effective plastic strain and corresponding yield stress (MPa) adopted in MAT_024

Stress \ Strain	0.0	0.002	0.006	0.012	0.03	0.07	0.14	0.20
0.076 mm foil	183	220	229	237	249	258	272	282
0.8 mm sheet	130	155	166	177	195	218	231	242
3.2 mm sheet	70	78	90	105	121	145	167	182

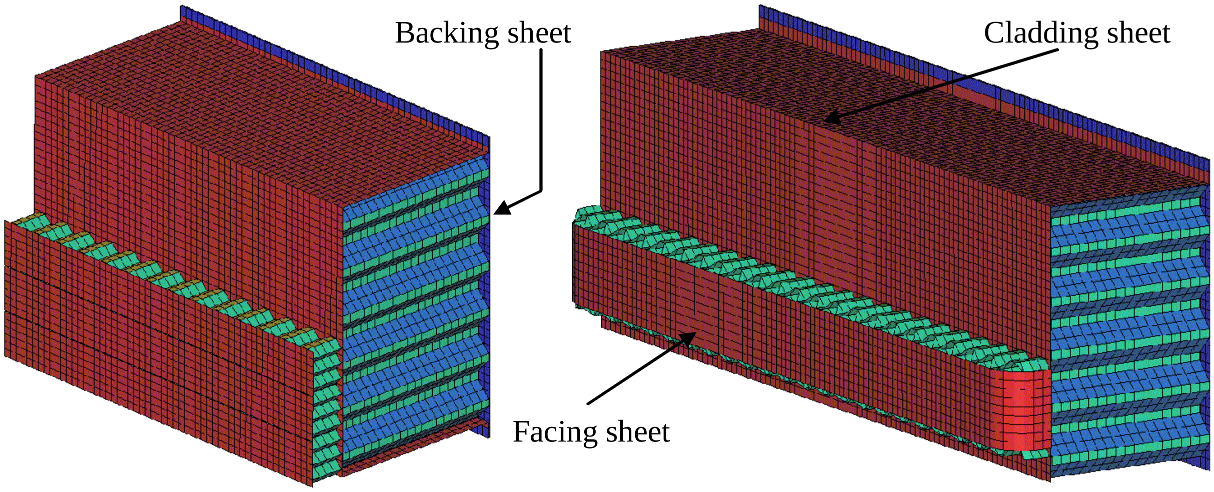


Figure 3. Base mesh alternatives with about 30 000 shell elements

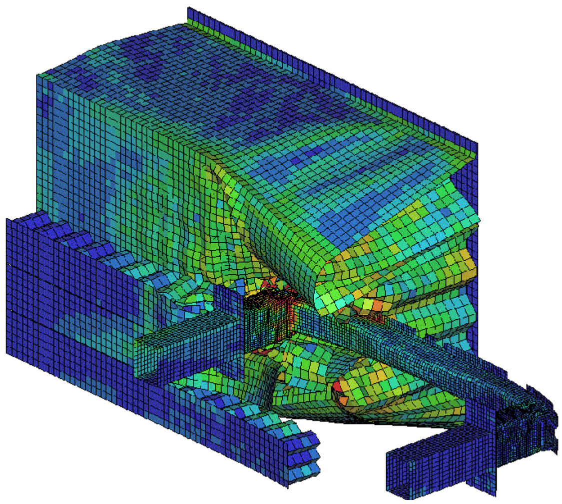
The backing sheet was modelled as rigid and some elements in the cladding sheet were fixed to represent the steel strips. Contact was included between the shells representing honeycomb and the facing sheets, the cladding sheet and the backing sheet, and the friction coefficient was chosen like 30 %. Moreover, the contact between the impacting beam and the barrier was modelled with friction coefficient equal to 50 %, while 10 % was used for the single surface contact that represented the internal contacts inside and between the honeycomb parts.

The adhesive was represented by one row of elements at each end of the honeycomb cells. These elements were not included in the contact definition, and their size was fitted to the contact thickness to directly support compression between the honeycomb parts and the aluminium sheets. The adhesive carries about 20 MPa in a lap shear test with two 170 x 25 x 1.5 mm aluminium strips and joint area 12.5 x 25 mm. However, this strength cannot be used directly since the shell thicknesses are scaled in the present barrier models. Thus, a simple bi-linear curve with yield stress 120 Mpa and tangent modulus 100 MPa was used to represent the tensile strength of the adhesive.

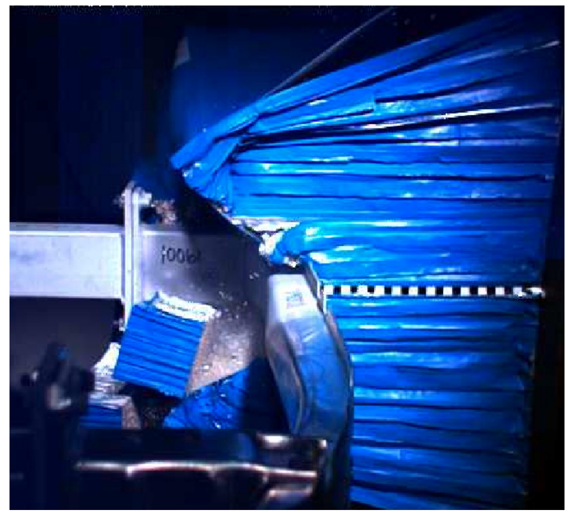
For the honeycomb main block and bumper elements the failure flag in MAT_024 was chosen like 50 % and 80 %, respectively. This effectively reduces the somewhat overestimated densification that is likely the result of the very coarse mesh. Note that the smallest cells are defined by only six shells over the cross section, and a higher value was necessary to avoid deleting a lot of elements and thereby significantly reduce the force level.

Results and Discussion

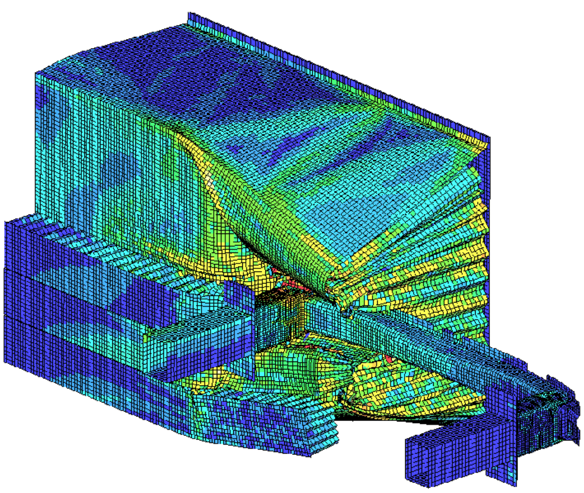
A short beam is impacting the offset deformable barrier. The beam hits the upper bumper element as well as some millimetre of the middle one, and it is fixed to a testcar with total weight 2000 kg and initial velocity 18.6 km/h. The car movement is free during the last part of the crash event. Thus, the boundary conditions are complex since the car rotation is influenced by parameters like its inertia, friction coefficients and force components that are again a result from the barrier as well as the beam deformation. Herein, both the test and the simulations show final car rotation about five degrees. Some numerical results with the base model as well as a refined alternative with half the cell size are presented in Figure 4. Both simulations seem able to represent the global behaviour of the ODB barrier, but the effect of tearing of the upper facing sheet and the densification at the end are both somewhat overestimated. The refined model does not give better correlation with the experimental force-displacement curve, but it predicts more local phenomena.



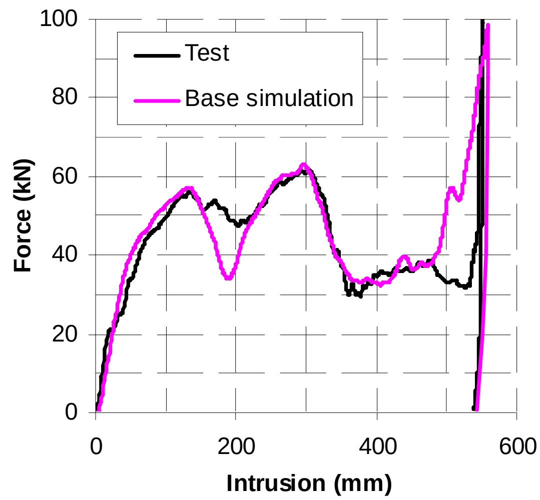
(a) Base simulation at 290 mm intrusion



(b) Test at 290 mm intrusion



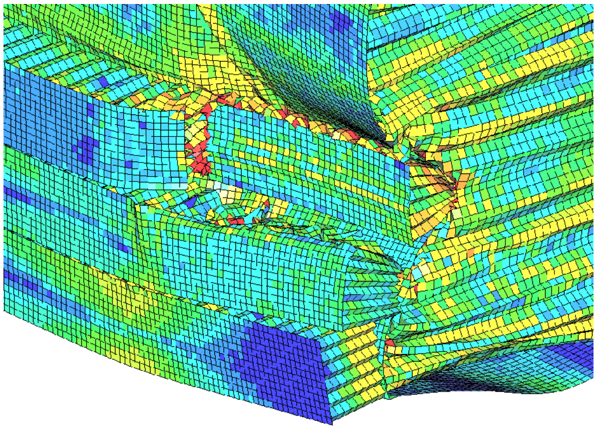
(c) Refined simulation at 290 mm intrusion



(d) Response curves

Fig. 4 Simulations and test of a short bumper that impacts the ODB barrier

Numerical simulations can be used to study how the different parts are deforming under the crash event. As an example, it may be visualised how the cladding sheet is deformed when some of the upper bumper element is forced into the main block. Figure 5a also shows how the upper facing sheet is cut as a result of the short beam. Thus, Figure 5b shows a photo after the test.

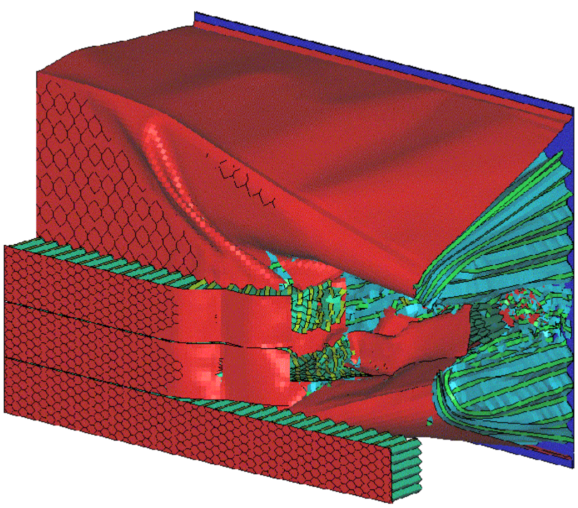


(a) Refined simulation at 170 mm intrusion

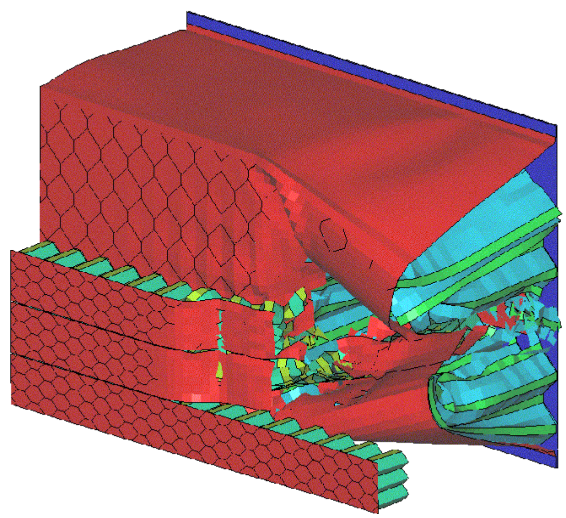
(b) Photo after the test

Fig. 5 Illustration of more local phenomena

Details like the wrinkles at the cladding sheet or the vertical contraction of the main block are more or less captured by the numerical models, see Figure 6. Thus, the tearing in the two upper bumper elements and the fracture development in the cladding sheet is represented. Modelling of fracture in the adhesive is another challenging task. Herein, it is likely that the friction in between the parts has influence on how the separation propagates.



(a) Refined simulation



(b) Base simulation

Fig. 6 The offset deformable barrier after the numerical crash event

In the second case the NHTSA side impact barrier is fixed to a testcar with weight like 1100 kg. The car moves along the strong axis of the honeycomb structure, it has initial velocity 35 km/h and it hits a rigid flat wall. The deformation mode at maximum intrusion is depicted in Figure 7. The force-deformation curve correlates well with the test result [5].

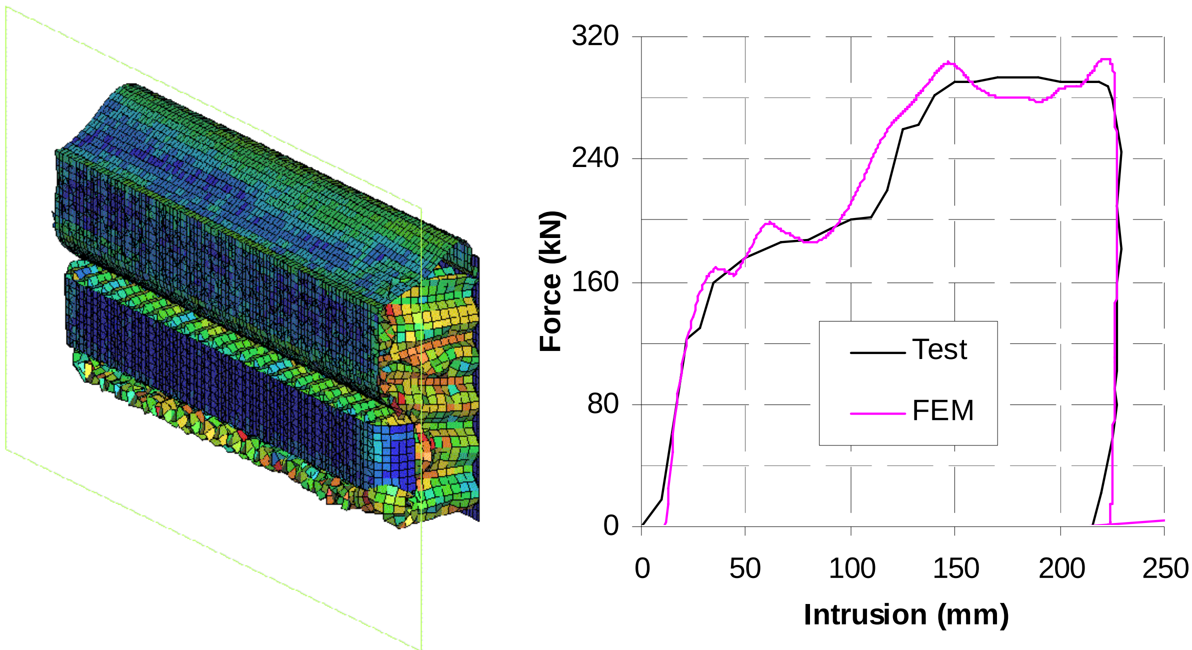


Figure 7. Side barrier impact into a flat rigid wall

Non-uniform loading should be of interest also for the side impact barrier, and it may be an idea to run it into a rigid pole. The simulation illustrated in Figure 8 is run with weight 1100 kg and initial velocity 35 km/h, and this seems sufficient to fully compact the barrier in front of the pole. The predicted deformation mode indicates fracture in the adhesive as well as in the facing sheet.

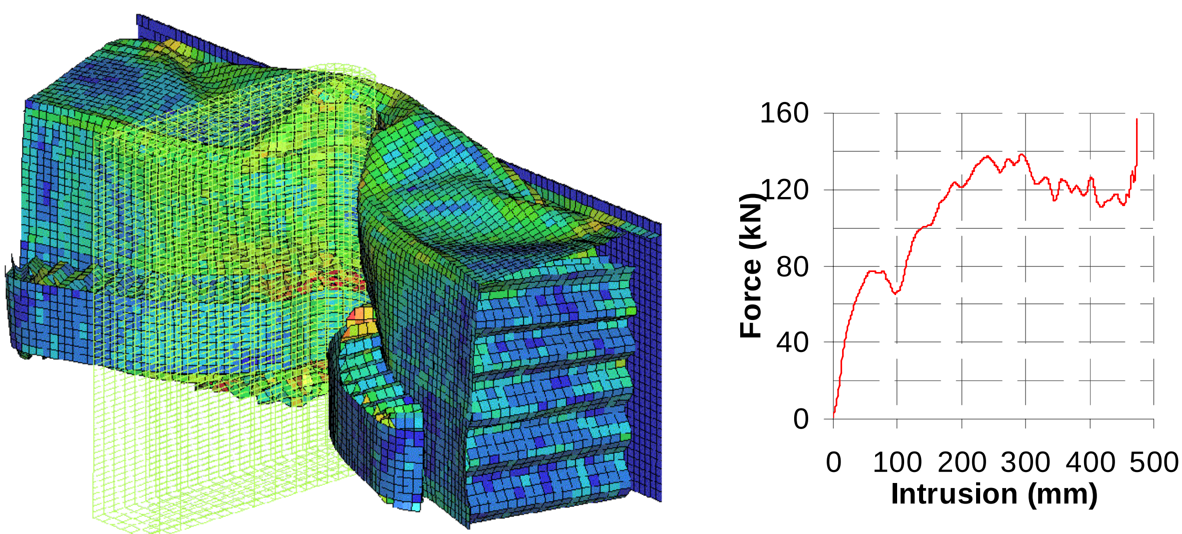


Figure 8. Side barrier impact into a rigid pole

Conclusion

In frontal offset and side impact collisions the honeycomb material is compressed not just along its strong axis, but also in the oblique direction. Thus, when the honeycomb structure is folded this may be seen as the interaction between local and global buckling of the cell structure. Therefore, the idea was to make barrier models based on shell elements, and use extensive scaling to achieve a reasonable computational cost. The presented models with about 30 000 shell elements seem able to predict the global response for the offset deformable barrier and the NHTSA side impact barrier, and these models can easily be refined to represent the more local behaviour as well.

References

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