USE OF HIGH EFFICIENT ENERGY ABSORPTION FOAM IN SIDE IMPACT PADDING

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ABSTRACT

In side impact events padding is often utilised to not only absorb energy but also push the dummy into motion. The padding is usually applied in the pelvic, the abdomen and the thorax area. The amount of absorption versus push load is important to obtain acceptable levels of the injury parameters as stipulated by legislation (e.g. ECE R95, FMVSS 214) and consumer tests (e.g. EURO/US-NCAP and IIHS). Practice shows many types of foam padding designs which fulfil the requirements, often in combination with side airbags.
In this paper the advantage of applying high efficient energy absorption foams in padding is presented. This enables designers of passive safety systems not only to save space, weight and cost but also increase safety (ratings) by having a better defined and more easily tune-able loading system on the dummy during side impact crashes.
Computer Aided Engneering (CAE) simulation methodology can be used efficiently to optimise part design. A case showing the benefits of high efficient energy absorption foam padding is discussed.

INTRODUCTION

Side impact crashes are one of the most severe accidents and account for roughly 30% of all fatalities in road accidents involving passenger cars and light trucks. For this reason, in many countries legislation has been put into place with minimum requirements for injury parameters in side impact crash tests. On top of this, consumer test ratings like Euro-NCAP and insurance testing have generally put higher requirements on side impact crash performance of cars. For example the recent upgrade of the IIHS side impact test in which the deformable barrier impactor has comparable dimensions to those of the front of a light truck, giving a much more severe impact collision than it used to be with the old barrier.

In addition, an increasing consumer awareness of safety is allowing automakers to utilize consumer and insurance test reports as a powerful marketing tool.

In view of all this, the trend of increasing level of passive safety measurements is clear. Even in the lower end vehicle segments, airbags are incorporated more often for frontal and side impact protection. In higher end vehicle segments, active safety systems are being introduced to the market and have found their application. However there is still a large number of vehicles built without side airbags, in specific regions such as North America and emerging markets. Therefore it is still necessary to engineer passive energy absorbing countermeasures utilizing foams solutions to provide occupant protection during side impact collisions.

Since the layout of safety systems greatly influences the design and styling of a vehicle it is important to know the performance of such systems and have a reliable tool for evaluation early in the design stage.

In the present study the advantage of using high efficient energy absorption foam in side impact protection is presented. First, an example of a recently developed energy absorbing foam is discussed. Then the development of the material models to accurately simulate this material in LS-DYNA is described. Subsequently a case is presented and conclusions are listed.

HIGH EFFICIENT ENERGY ABSORPTION FOAM

The foam considered in the present paper is a closed cell, styrenic foam, specially developed for energy absorption in automotive applications. It is produced via an extrusion manufacturing process and commercialised under the trade name IMPAXX™ energy absorbing (EA) foam. The continuous extrusion production process ensures a constant quality and a high level of consistency of the material properties. Foam boards are formed in the extrusion process from which parts (pads) can be cut by hot wire or abrasive wire cutting technology. This fabrication technique offers the additional benefit of eliminating the need for

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expensive forming tools associated with traditional foam solutions.

A typical quasi-static stress-strain characteristic of the foam is depicted in Figure 1.

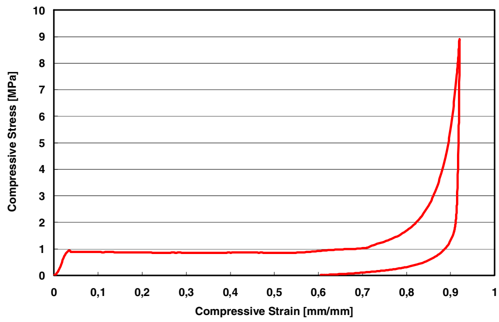

Figure 1. Quasi-static stress-strain curve for IMPAXX™ foam.

The stress ramps up rather fast and then remains constant, up to 70~80% compression. From then on the material densifies and the stress increases rapidly. Due to this behaviour, the material can be categorised as high efficient energy absorbing since the stress-strain curve is nearly a block curve and an ideal absorber would show a square wave response.

In Figure 2, a comparison is given between IMPAXX™, expanded Polypropylene (ePP) and semi-rigid Polyurethane (PUR) foam, all of similar densities.

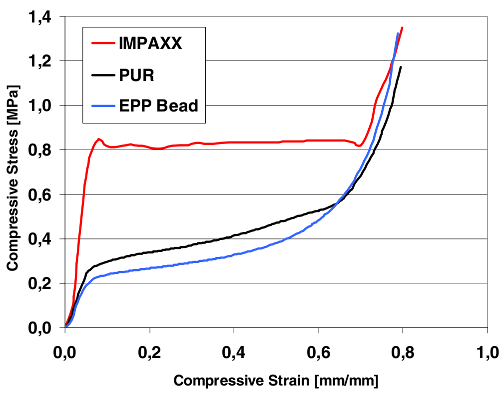

Figure 2. Compression curves of IMPAXX™ in comparison with ePP and PUR foam for equal density.

Due to the square-wave response of IMPAXX™ foam it is clear that it is a more efficient solution compared to ePP and PUR foams. This is illustrated in Figure 3 where the efficiency curves of the mentioned materials are shown.

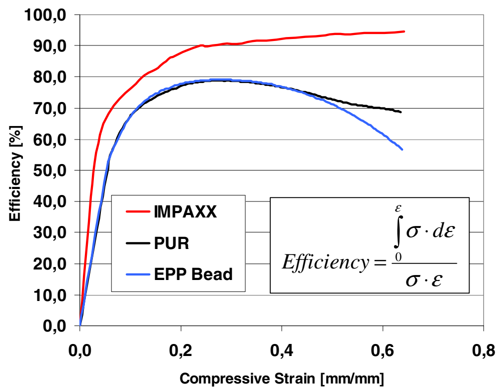

Figure 3. Comparison of efficiency curves.

Increasing the density of ePP or PUR to achieve the same compressive strength of IMPAXX™ foam would, not only increase the effective weight of the EA part, but also speed up the densification, thereby further decreasing their efficiencies. Therefore, besides maximising the energy absorption and minimising the packaging-space required to absorb a given amount of energy using IMPAXX™ foam, significant weight savings can be realized as well.

Another positive attribute is the stable performance over a wide temperature range as illustrated in Figure 4.

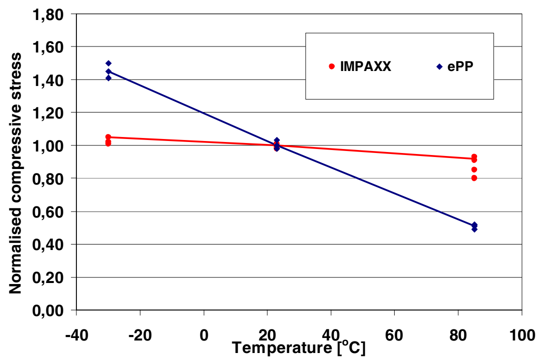

Figure 4. Normalised compressive stress over temperature.

It shows that over a wide temperature range from -35 °C up to 85 °C IMPAXX™ has a constant performance.

MATERIAL MODELS FOR CAE

Because computer simulations play a big role in modern vehicle development, it is important that trustworthy material models are available. This section describes briefly the material model validation of IMPAXX™ EA foam.

Parameters for LS-DYNA material model Type 63 (*MAT_CRUSHABLE_FOAM) [1] were identified for each foam grade from drop tower tests with a flat impactor, see Figure 5, to obtain high strain rate stress-strain curves, see Figure 6.

Figure 5. Drop tower test set-up.

The smoothened average compressive stress-strain curves were used as input load curves for the material models.

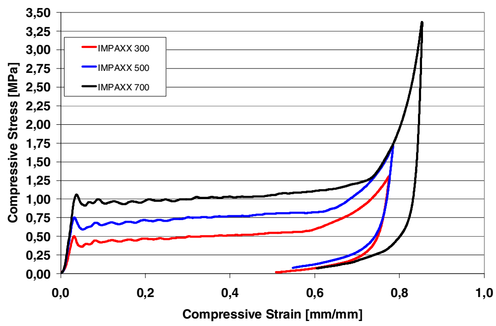

Figure 6. Average dynamic compressive stress-strain responses for IMPAXX™.

Pelvic shaped impactor tests, see Figure 7, were performed for validation of the models.

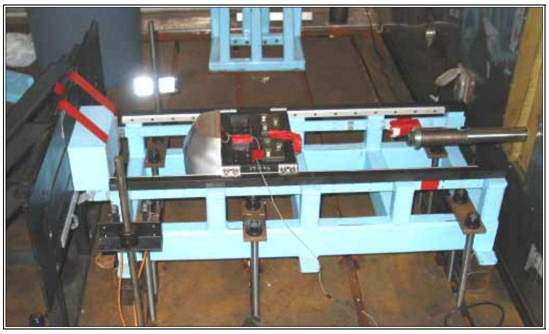

Figure 7. Pelvic impactor test set-up.

These tests were done on several sample geometries: blocks, cones and pyramids, see Figure 8.

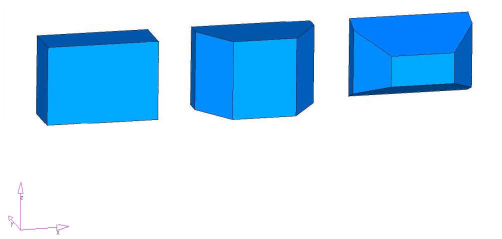

Figure 8. Sample geometries for the pelvic impactor tests: block, cone and pyramid.

Finite element models for the drop tower test, see Figure 9, and the pelvic impactor test, see Figure 10, were created and the tests were simulated.

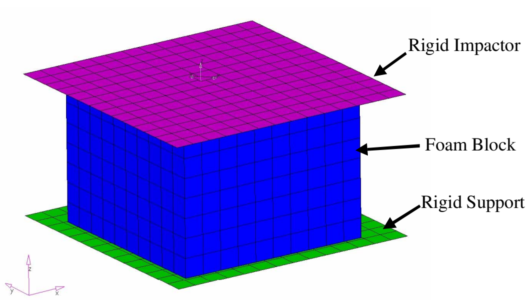

Figure 9. Finite element model of the drop tower test set-up.

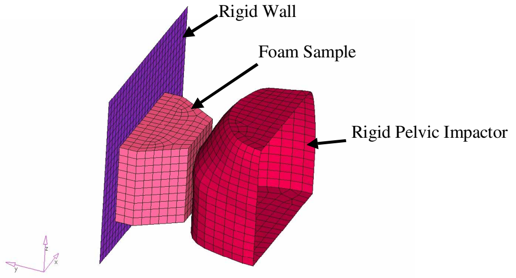

Figure 10. FE Model of the pelvic impactor test set-up.

Figure 11 to Figure 14 show simulation results versus tests for IMPAXX™ 700 of drop tower tests and pelvic impactor tests.

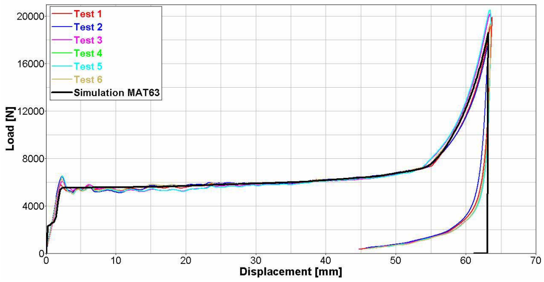

Figure 11. Drop Tower Test vs. Simulation for IMPAXX™ 700.

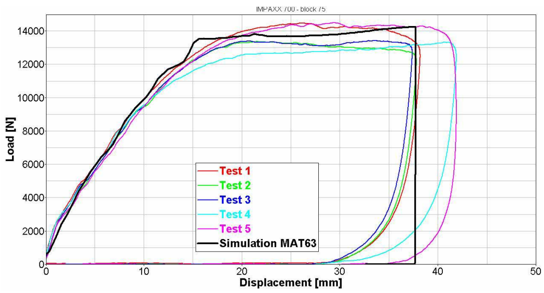

Figure 12. Pelvic impactor tests vs. simulation on 75 mm thick IMPAXX™ 700 blocks.

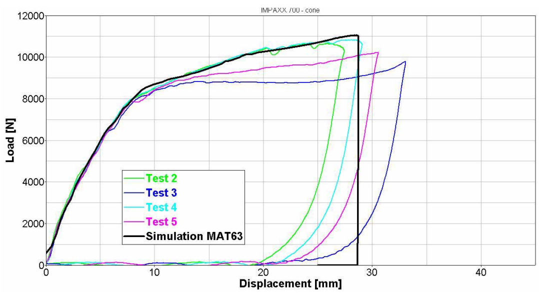

Figure 13. Pelvic impactor tests vs. simulation on IMPAXX™ 700 cone samples.

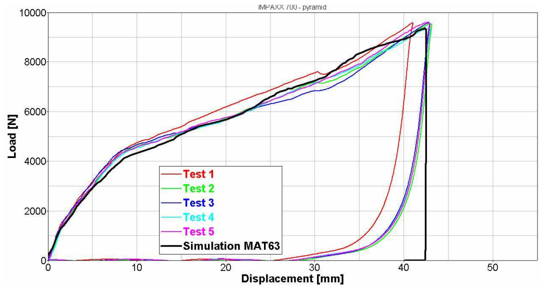

Figure 14. Pelvic impactor tests vs. simulation on IMPAXX™ 700 pyramid samples.

All cases show a very good correlation of the impactor's load and displacement level between test and simulation. The models can be used with confidence.

SIDE IMPACT CAE OPTIMISATION CASE

In many cases car manufactures obtain door modules from a supplier who is then also responsible for the development with respect to safety. In these cases, the door system is required to give a certain load-intrusion characteristic to a rigid impactor. This characteristic is then defined for the pelvic, abdomen and thorax area and is such that it will achieve the appropriate loads during side impact to the dummy to result in the targeted level of injury parameters. Figure 15 illustrates a typical pelvic impactor load-intrusion requirement for a door panel.

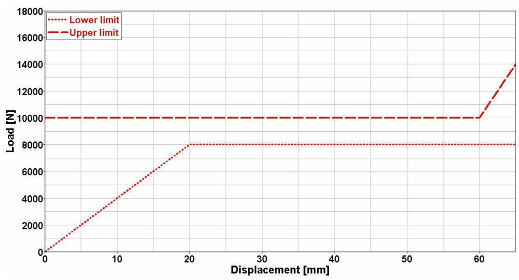

Figure 15. Typical load corridor specified for rigid pelvic impactor.

The door module supplier is required to prove the right load-intrusion characteristic by CAE simulations and by testing. Testing is defined on the door module as follows. A rigid pelvic shaped impactor hits the door module with a defined initial velocity and the impactor acceleration is recorded.

Acceleration and displacement are calculated from the load and thus obtained load versus displacement must fit in the defined corridor. The test is usually done on a drop tower or on a sled test set-up. Figure 16 illustrates a drop tower test set-up with a rigid pelvic shaped impactor.

Figure 16. Drop tower with pelvic impactor.

The pelvic impactor test set-up of the discussed door module is modelled, see Figure 17 and contains all components of the door, the door-in-white and the rigid pelvic impactor.

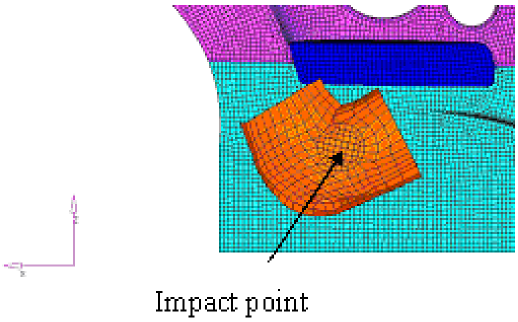

Figure 17. Side impact CAE door model.

Starting with a relatively large foam pad, the optimum shape is found by reducing the size and changing the location. The optimum shapes from fabrication point of view are square parts (blocks). Usually the door trim is rather flat which means that if the pad is attached to that side, it also can be flat. Usually the door-in-white has a complex geometry, however if during a side impact crash the barrier starts pushing the car, the door-in-white is pushed and deforms and will move as a flat surface, even if it is not flat in the original position. This means that also on the side of the door-in-white, the foam padding can be flat. Usually, the whole part can be kept simple and block shaped. For the case discussed here, the size of the part was optimised, such that the pelvic load response was in the corridor, see Figure 18.

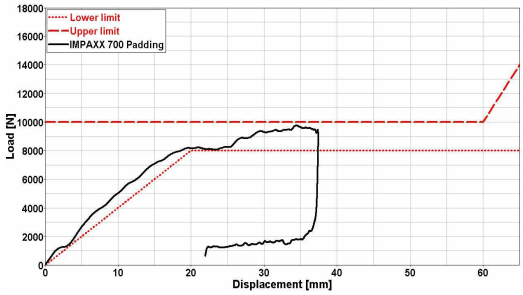

Figure 18. Pelvic impactor load response for an optimised foam pad.

In Figure 19 a cross section of the simulation model at four stages during the pelvic impact is shown.

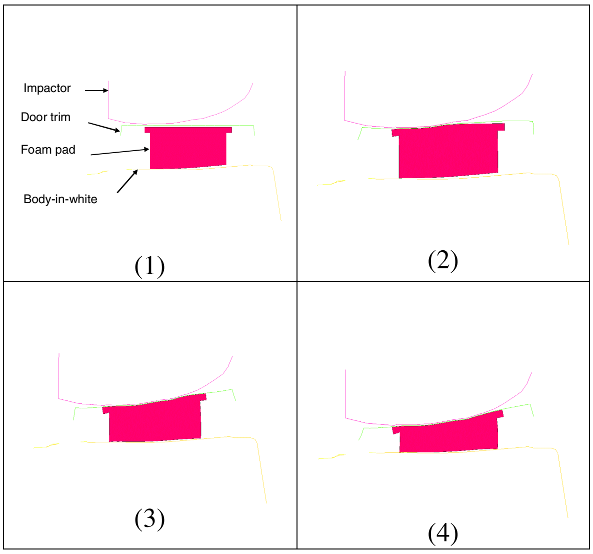

Figure 19. Pelvic impactor intrusion; horizontal cross section through the H-point.

At stage (1) the impactor has just made contact with the door trim, displacement is 0 mm. At stage (2) the impactor has moved further, the load has ramped up and is going towards 8 kN at 20 mm displacement. At stage (3) the impactor has moved 20 mm and the contact area between impactor and foam pad is maximal. When the impactor moves further, the load does not increase significantly; the compression area is constant and the stress level is constant until the foam enters the densification area at about 70% compression. This means that up to that point a nearly perfect load control is possible, see Figure 18.

This case illustrates a relatively easy method of optimizing the part design of an energy absorbing foam countermeasure pad using an efficient solution such as IMPAXX™ foam.

CONCLUSIONS

Use of high efficient energy absorption foam for side impact protection is presented. These materials have great advantages to be used in development of side impact padding:

- Improved load control. Due to the square-like compression stress-strain response of the foam, a nearly perfect load control can be established. This enables design of robust side impact pads.
- Accurate material models exist to simulate parts in CAE analyses. This means that in the development process CAE can be leveraged to optimise an EA countermeasure part design using both geometry and density.
- Short development times. First, with use of accurate CAE models enables more accurate, virtual testing and save on testing time and cost. Secondly, prototypes can be produced easy, quick and cost effective since no tooling is necessary.
- Prototypes are equal to production parts since the way to produce both are the same; by hot or abrasive wire cutting technology. Also during testing it is easy to modify prototypes and an optimum can be found iteratively on the testing spot as well.
- Weight savings up to 50% are possible since high efficiency results in smaller part with same performance. On top of the smaller part size, the density is general lower. For example, to obtain the same load response with ePP the densities need to be twice as high. Although this is not safety related, fuel consumption efficiency as a result of lower car weights is nowadays highly appreciated.
- Packaging space saving since the padding can be smaller. If this is taken into account early in the design process, it is possible to use the extra space, e.g. for enlarged door pockets.

REFERENCES

[1] LS-DYNA User Manual, Livermore Software Technology Corporation.

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