CLOSURE AND TRIM DESIGN FOR PEDESTRIAN IMPACT

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ABSTRACT

To provide protection to pedestrians in collision with passenger vehicles, the design and construction of a vehicle's bumper, hood and fender panels must be addressed. TNO has undertaken a research project in conjunction with DSM to investigate how this may be done.

Vehicle styling, packaging and an analysis led design process will be shown for the front of the vehicle and in particular the hood and bumper. The recommendations of EEVC working group 10 are used as a target to asses the design proposal's suitability.

INTRODUCTION

Each year around seven thousand pedestrians are killed in European road accidents [1]. A high proportion of these fatal accidents involve passenger cars. In response to this the European Enhanced Vehicle-safety Committee has proposed a test method [1,2] (fig.1) based on their research to assess the protection offered to vulnerable road users by the front of passenger cars.

As the crash safety of pasenger cars has increased dramatically the last decades, the weight of the vehicles has also increased. In a joint initiative between several companies from the Netherlands, new concepts for a vehicle front with enhanced safety features were developed, with the aim to decrease the mass of the vehicle front. This so called 'Ecofront' project was part of a bigger project in which a complete vehicle concept was developed. Besides the reduction of weight a second objective was to meet the severe requirements for crash safety. Two aspects were covered, frontal impact protection [6] and pedestrian protection.

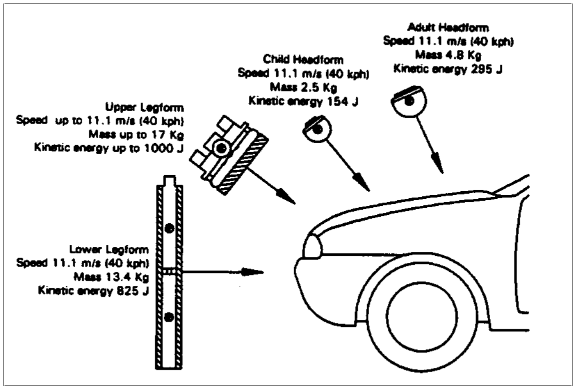

Figure 1. Pedestrian protection testmethods proposed by EEVC WG10

In this paper only the development of the Ecofront with respect to pedestrian safety will be described. Designing a bonnet, fenders and a bumper which satisfy the proposed EEVC pedestrian requirements is very much dependant on the availability of enough deformation space. In most cars the deformation space is limited and increasing the available space can seriously compromise the styling and packaging of the vehicle. During the design of the Ecofront, styling and packaging were taken into account. Pedestrian, pendulum [5], 'Allianz' [7] (low speed insurance test) and component handling requirements were assessed with the use of computer simulations.

As a final result of this project a demonstrator (fig.18) has been built to show the feasibility of the newly developed concepts.

This paper will give an overview of the work performed to achieve the described objectives in the following chapters: Conceptual Study, Design

Solutions, Bonnet Materials Research, Bonnet Development and finally the Bumper Development.

CONCEPTUAL STUDY

A first exterior surface for the Ecofront was created based on general design guidelines, which were based on TNO experience (i.e. from previous projects and testing). These general design guidelines included the nessesary free deformation space underneath the bonnet and behind the bumper surface. This first exterior design was used to make an initial assesment of the pedestrian safety of the vehicle shape, which was performed using MADYMO multibody techniques and MADYMO models of the EEVC pedestrian impactors [3]. The main objective of this first assesment was to provide guidelines for package design.

Conceptual studies were performed on two areas:

- Bumper and Bonnet Leading Edge (BLE) Study
- Bonnet Study

Conceptual Bumper and BLE Study

The Ecofront was modelled by four ellipsoids (fig.2), and simulated impacts with the upperleg and leg impactor were performed. The four ellipsoids represented the three important areas of the Ecofront; spoiler, bumper and bonnet leading edge. By using the optimisation software within MADYMO (MADYMIZER) several optimisations of the bumper system were performed to find the right balance in stiffness between these three important areas. In these optimisations the stiffness and the stroke of the three ellipsoids were chosen as variables and the constraints were based on the maximum allowed values according to the proposed EEVC test method. The objective of the optimisation was to minimise the amount of deformation in the bumper whilst achieving the proposed EEVC pedestrian requirements. In this study both leg and upperleg were considered at the same time, because the optimal vehicle front stiffness for each load case differs. The bonnet leading edge stiffness is mainly dependant on the requirements of the upperleg impactor. To prevent too much bending of the lower leg impactor, the bumper and spoiler stiffness will then need to be adjusted. This whole process of changing the stiffnesses of these three main areas was a fully automated process within MADYMIZER and resulted in the highest possible stiffness for the bonnet leading edge, bumper and spoiler in

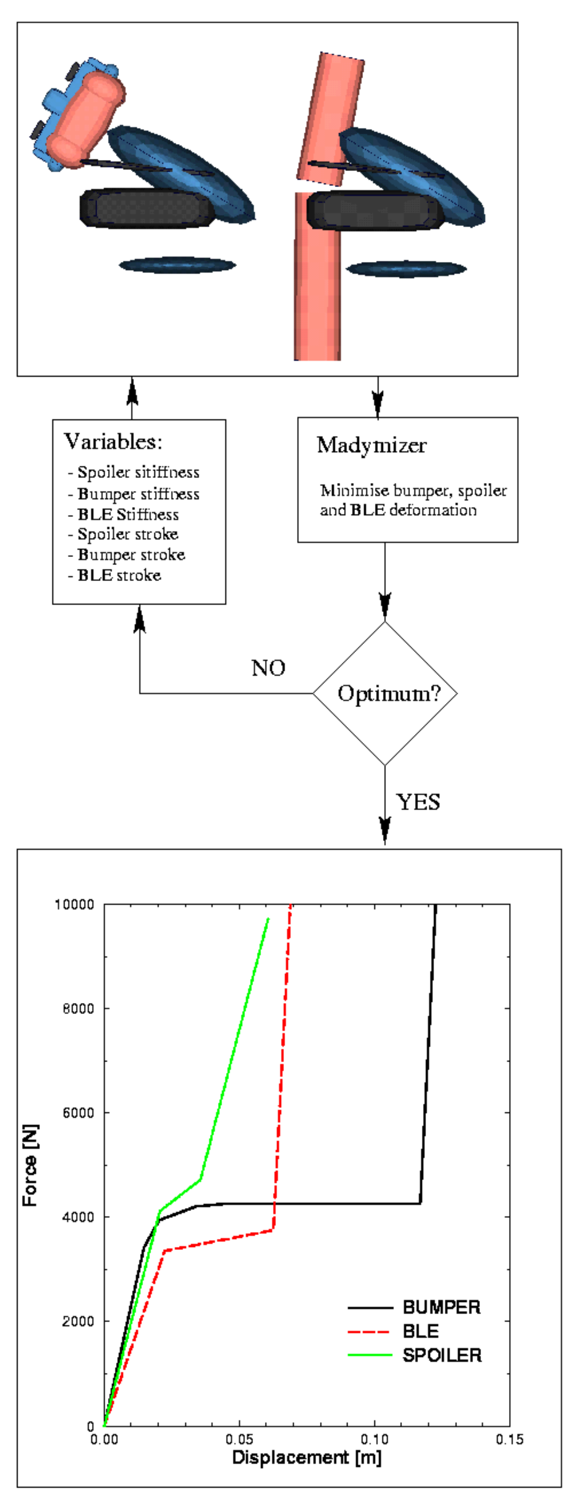

Figure 2. Conceptual bumper and optimisation

combination with the lowest possible deformation. This whole optimisation process is schematically shown in figure 2. The output of the optimisation has been used as guidelines for package design and further development of the bumper to create the maximum possibility of finding an engineering solution for the design of components once the exterior surface has been chosen.

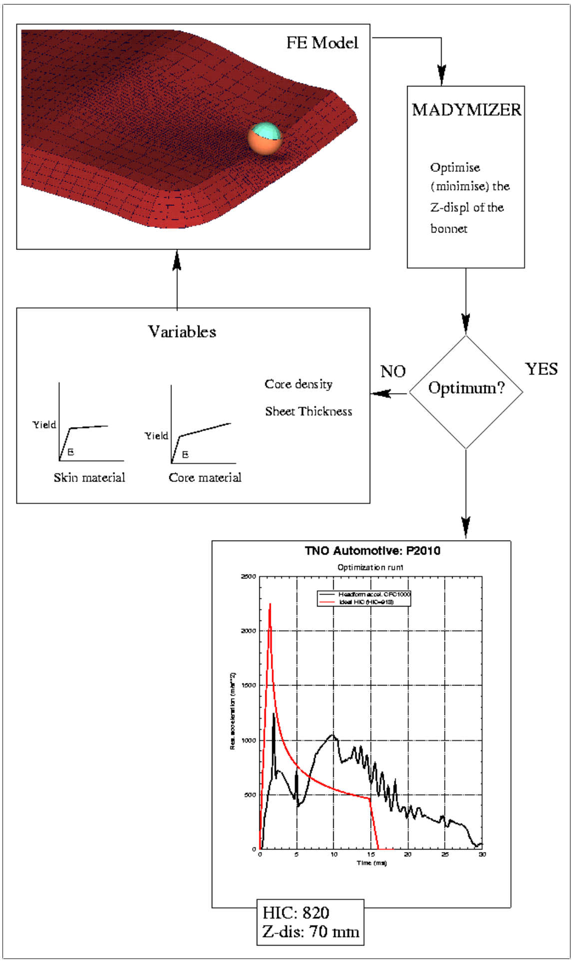

Figure 3. Conceptual bonnet optimisation

Conceptual Bonnet Study

The objective of the conceptual bonnet study was to achieve a HIC value below 1000, with the lowest possible deformation for simulated head impacts, by changing the material properties of the bonnet.

For this purpose a MADYMO FE model was built from a first representation of the bonnet surface. The outer surface was modelled by shell elements, for the inner structure a representation with solid elements was made for ease of geometry and material properties variations. Simulated child head impacts were performed with a ’Facet’ (see figure 10, right half) representation of the headform [3] as described in the proposed EEVC test method.

With this FE model, MADYMIZER optimisations were performed (fig.3). The variables in this optimisation were, E-modulus, Yield stress, sheet thickness and depth of the solid elements representing the materials used for this bonnet. The optimisation resulted in a theoretical material with which it was possible to decelerate the head-impactor efficiently for a certain geometry.

DESIGN SOLUTIONS

Based on the results of the conceptual studies design recomendations were made for three areas;

- Necessary free space underneath the bonnet to avoid contact with rigid engine parts;
- Necessary free space between bumper skin and aluminium bumper beam;
- Location of the joints between the outer surface panels. These joint locations normally create local stiffnessess in the impact zone, which make it difficult to achieve the proposed EEVC pedestrian safety requirements.

Surface evaluations were performed with Ideas Master Series. The first design proposal of the styled surface, created within Alias, was used to determine the impact areas for leg, upperleg and head impacts according to the proposed EEVC test procedure (fig.4) and to check the underbonnet clearance. These evaluations resulted in a modified styling which moved the splitlines outside of the impact zones.

Special attention was paid to the headlight units which were placed further back (fig.5). As such free space was created, on one hand allowing sufficient deformation for the leg and upperleg impacts on the front of the car and on the other hand to ensure that the headlight lamp unit stays undamaged in case of a ‘Allianz’ insurance test [7].

As hinges normally create local stiffnesses in the impact zone which make achieving the proposed EEVC pedestrian requirements for head impacts difficult, the hinges of the bonnet were placed outside of the impact area. This was possible because of the chosen styling, see figure 6

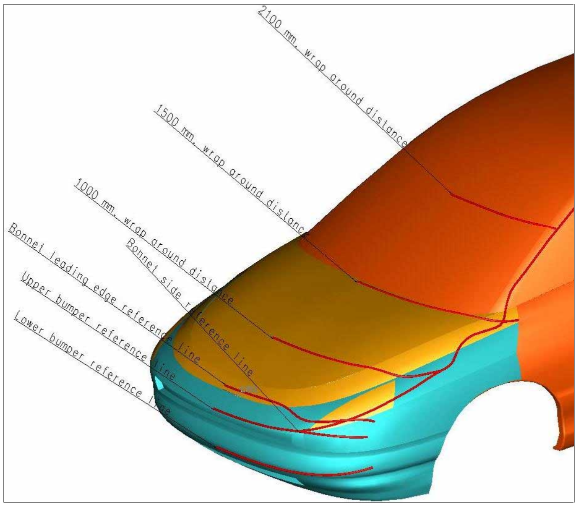

Figure 4. Surface evaluations

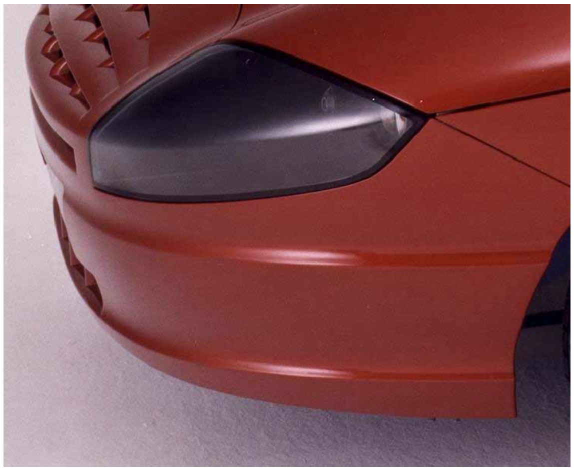

Figure 5. Head light design

Figure 6. Hinge design

BONNET MATERIALS RESEARCH

The results of the conceptual bonnet study show that it could be possible to find material solutions for bonnets to decelerate a pedestrian's (child) head efficiently. Therefore TNO-Automotive initiated a research project in conjunction with Centre for Lightweight Structures TUD-TNO to determine materials which could lead to effeciently decelerate a pedestrian headform, using a lightweight panel.

As a basis for this materials research project a so called ideal HIC deceleration function [4] was used (see fig.7). Also it was found that initial accelerations above 250g [4] were unacceptable in order to avoid skull fractures. The efficient deceleration of a headform should be independant of the place of impact on a bonnet panel. Therefore a homogeneous stiffness disitribution over the panel was found to be important. Based on these assumptions several ideas for combinations of different materials were generated. These material combinations resulted in a number of different panel constructions.

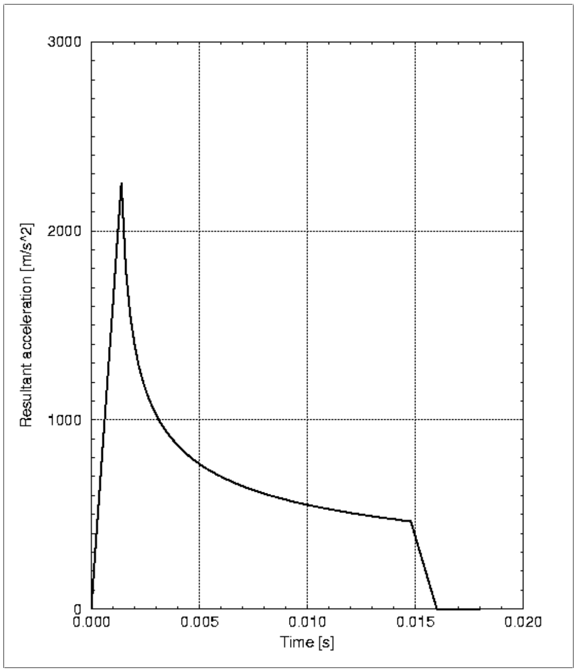

Figure 7. Ideal deceleration curve

To asses the feasibility of the different panel constructions, it was nessesary to understand the first principles of head impacts. Therefore a study was performed with a MADYMO FE adult headform impacting a flat plate and a curved plate. The most remarkable finding of these simulations was that the FE simulation of the head impact on the flat plate showed a second peak in the head acceleration. This peak was found to be a function of the bending wave which traveled through the plate. This wave travels to the edge of the panel and travels back again and then hits the impactor for the second time, where as on the curved plate snap through was observed.

Based on the knowledge from the first principle examination, several simulated MADYMO FE head impacts were performed on different panel constructions to asses their decelerating capabilities in order to make a selection of the most promising constructions.

In total twelve square test panels of 0.5m x 0.5m of the four most promising constructions were created. Impacts were performed on the panels with a guided rigid sphere of 4.8 kg with impact speeds varrying from 8.3 m/s to 11.11 m/s, with the panels simply supported on a square testrig. The test setup is shown in figure 8. The test results were used to validate the FE models to be confident in the predictability of those FE models when being used in further bonnet development.

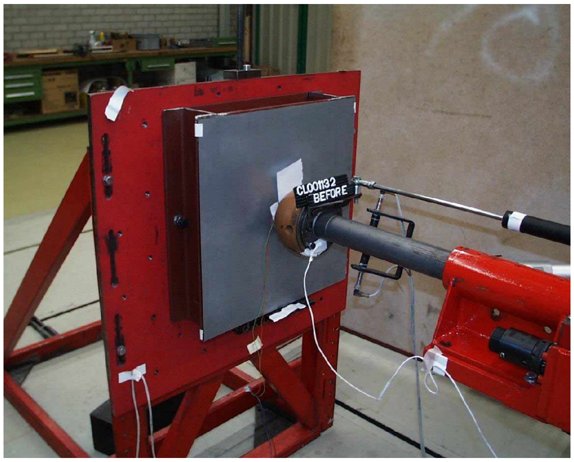

Figure 8. Test setup

The four types of panel tested were all sandwich like constructions. The sandwich was chosen to provide a homogeneous stiffness distribution all over the panel. All panels had a steel upper layer to stimulate the generation of a relatively high initial peak acceleration of an impacting headform. Depending on the type of sandwich panel, different collapse mechanisms (i.e. breaking, denting) will generate the so called 'Ideal' deceleration function. The sandwich panel itself should provide sufficient bending stiffness for handling and to avoid low frequency vibrations.

Two tested panel constructions will be discussed in detail in this paper and will be refered to as:

- Multi-layer panel
- Two layer panel

In case of a multi layer panel the top layer was a 0.7 mm steel plate, the bottom layer a brittle Bulk Mould Compound (BMC) and between these two layers 5 mm of PVC foam. The two layer panel is identical to the multi layer panel, but without PVC foam. The foam keeps the skins apart and transmits shear stresses. On impact, through deformation of the steel plate, the lower skin fails and subsequently the foam core as well, allowing local bending deformation. The behaviour of the panels in the tests were similar to the behaviour as described above, however due to the timing of the material breaking for the multi-layer panel, the acceleration curves were not close to the ideal acceleration curve (fig.9). Also the avarage HIC value was 1600, which was a function of panel size and the support conditions. For the two layer panel the results were much better, HIC values of 600 and almost ideal acceleration curves.

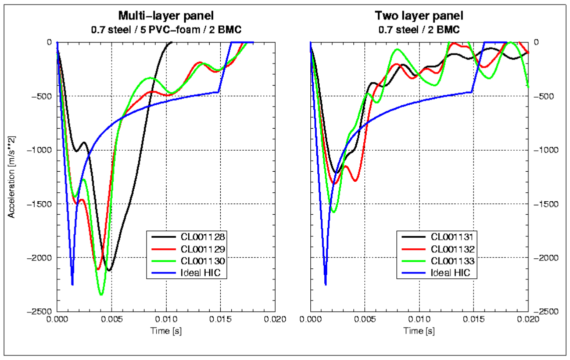

Figure 9. Test head impact accelerations

FE models of the multi and two layer panels were created and validated against the test results. Some impact test were performed on a single steel plate to be used in the FE model validation. Material input was mainly based on tensile tests. Obtaining the correct crash mode of the flat panel was of major importance for a valid FE simulation (fig.10).

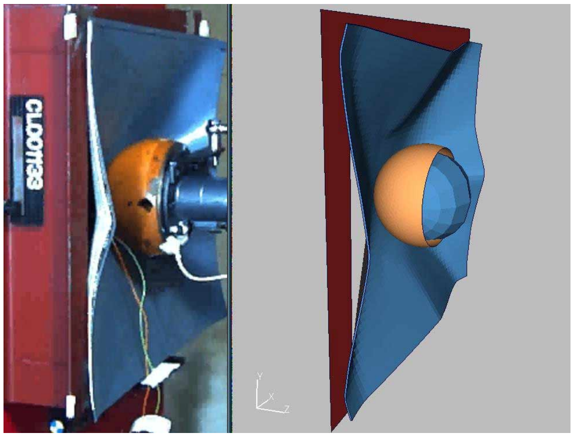

Figure 10. Comparison deformation modes

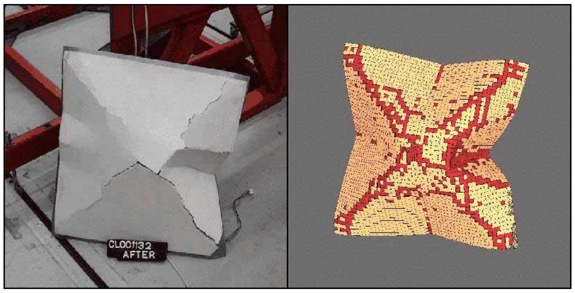

Figure 11. BMC damage

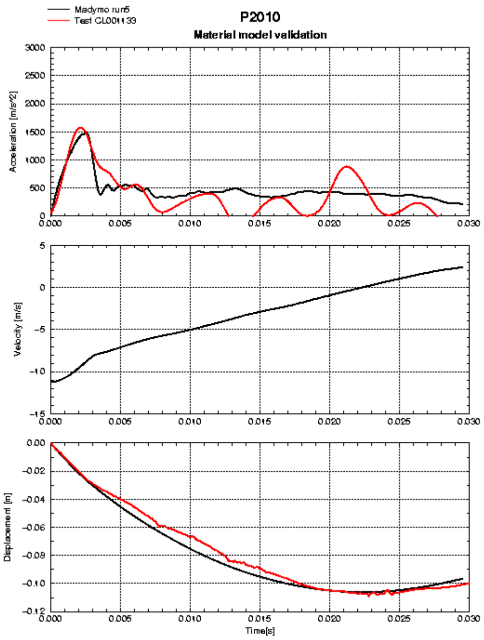

Figure 12. Validation of two layer panel

For the multi and two layer panels the damage properties of the brittle BMC layer were critical because the moment of breaking was crucial for a valid prediction and therefore needed to be modelled accurately. The cracks in the BMC are mainly dependant on the crash mode of the steel plate, which makes the prediction of the damage evolution more controllable (fig.11 and fig.12). As this phenomenon was assumed to occur in most head impact load cases, the MADYMO FE simulations were found to be predictive enough to be used in further bonnet development.

BONNET DEVELOPMENT

Based on the latest vehicle style, an assesment of the impact locations was made with the proposed pedestrian test method of the EEVC as a measure. According to this method the whole bonnet was to be considered as a child impact area. Based on the vehicle style and the results of the materials research a MADYMO FE model of the bonnet and surrounding structure was created (fig.13).

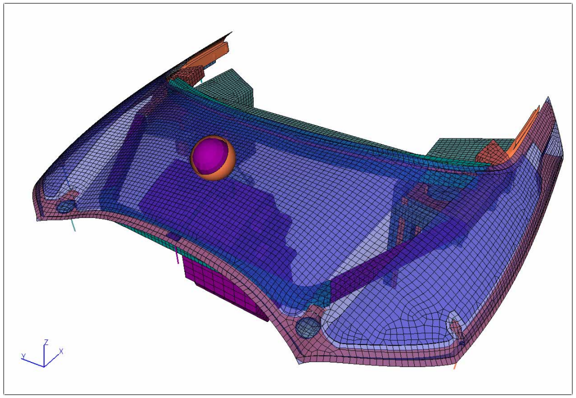

Figure 13. MADYMO FE model of the bonnet

In this FE model the bonnet consists of a 0.7 mm steel outer surface with a BMC layer on the inside. In the areas with less curvature a PVC foam was placed between the steel outer surface and the BMC to give the BMC an offset and thereby achieving a better stiffness in these areas.

Severeral child head impact simulations were performed at different locations on the bonnet. The child head was represented by a MADYMO facet model [3] of the physical child headform. By tuning the offset of the underlayer material (BMC) in most of the areas HIC values below 1000 were achieved, however for one particular area the HIC values varried from 1100 to 1200. This was mainly caused by the styling feature in that area, see figure 14. By smoothing the bonnet surface, HIC values below 1000 were found. Table 1 gives an overview of the achieved results on both the curved bonnet and the smooth bonnet.

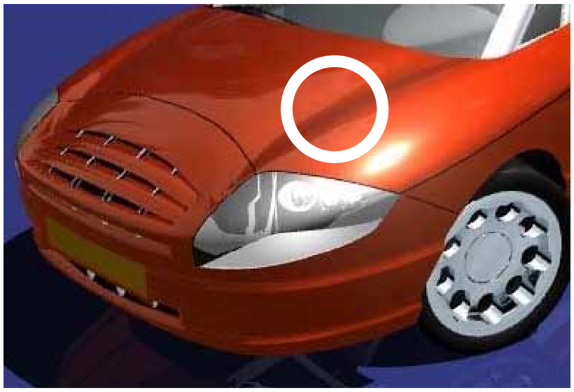

Figure 14. Styling feature

HIC values below 1000 can be achieved by tuning the offset of the BMC layer dependant on the amount of curvature in the panel. Looking at the shape of the HIC curves, the expected “ideal” shape is not completely achieved by choosing special material properties only. It seemed that the ideal HIC deceleration curve can only be achieved through a combination of material properties and certain global geometrical shapes.

Table 1. HIC results

Model	Position 1 HIC	Position 2 HIC	Position 3 HIC
Curved bonnet	920	1138	627
Smooth bonnet	716	938	755

Vibration FE analyses and static loading analyses with I-deas Master Series were performed in addition to the impact load cases. A static load of 40 kg was applied to the bonnet panel edge close to the windscreen, without support of the flexible plenum. The deformation was found to be 3mm, which was within the design target of 5mm. The first resonant frequency of the panel was found to be below the vibration frequencies of the engine.

BUMPER DEVELOPMENT

During the development of the bumper, both pedestrian and low speed impacts were taken into account. This led to conflicting requirements as the loading associated with low speed vehicle impact differs from the loading associated with pedestrian impact. This development was performed in conjunction with DSM Design & Application Development Centre. DSM was responsible for the manufacturability of the bumper skin and the pendulum impacts, TNO Automotive, who was overall responsible, took care of the crash safety aspects related to pedestrian safety and finding a compromise between differing requirements.

From the conceptual study it was clear that when satisfying pedestrian requirements, three main areas needed to be considered: spoiler, bumper and bonnet leading edge. To make a first assesment of the bumper system a MADYMO FE model was created of the bumper skin, the connections and the most important structural parts behind the bumperskin. Several simulated impacts were performed on different locations on the bumper with a MADYMO FE representation of the legform impactor [3] (fig.15). With just the bumper skin, which is made out of PolyPropylene (PP), it proved to be impossible to achieve a proper balance between bonnet leading edge, bumper and spoiler area. Therefore special energy absorbing elements, also made of the same material PP, were added behind the bumper surface. The advantage of this method was that the stiffnesses of each of the three main areas could be tuned seperately. Figure 16 shows an exploded view of the bumper system and figure 17 shows the results of the simulation.

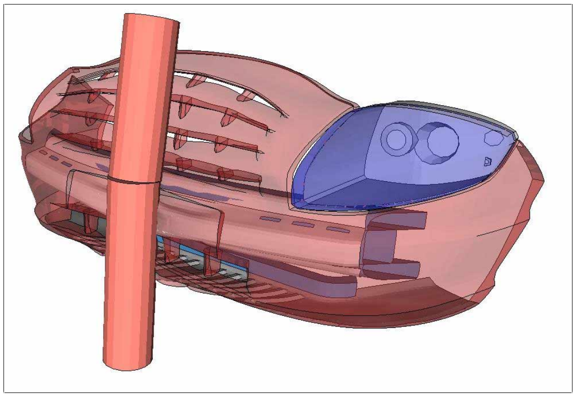

Figure 15. MADYMO FE simulated leg impact

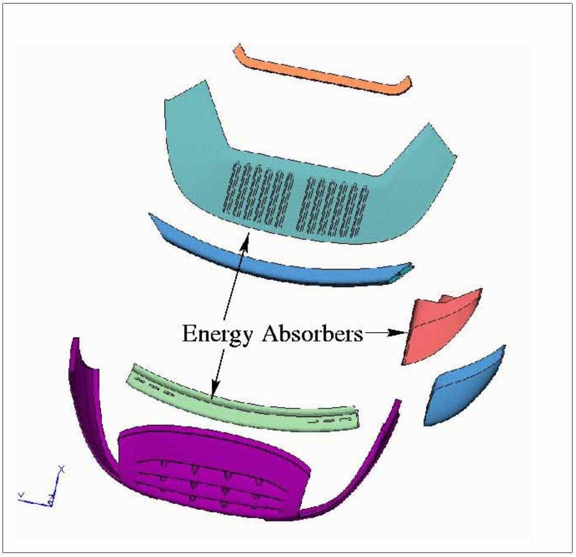

Figure 16. Exploded view of the MADYMO FE model

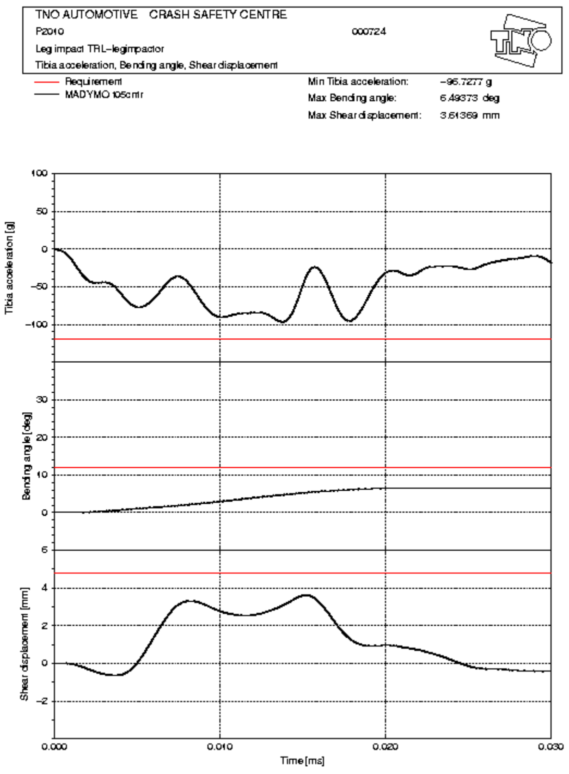

Figure 17. Centre leg impact FE results

FE legform impacts on the headlight were then performed. The light unit was found to be placed sufficiently rearward (based on the design recomendations) to be hit by the leg impactor. This gave the opportunity to design the light to be used as an energy absorbing element for pedestrian leg impact.

Allthough according to the proposed pedestrian test method of the EEVC no upperleg testing on the Ecofront bumper system would be required because of the Bonnet Leading Edge height, one MADYMO FE simulation of an upperleg impact was performed.

On all impact locations considered, within the simulations, in this study it was found to be possible to satisfy the EEVC pedestrian requirements. Physical testing is planned to validate the concepts.

The loading associated with low-speed pendulum impact [5] differs from the pedestrian impact loading. Absorbing legform impact energy requires a bumper system which absorbs the energy over the height of the bumper. Pendulum impacts work more in the width of the bumper. For that reason a stepped crash zone was introduced. The first part of the bumper deformation is used for pedestrian impact protection, the second part will absorb most of the pendulum impact energy. This is because the “soft” bumper is not capable of absorbing all of the pendulum energy. FE simulations showed that the aluminum structure behind the bumperskin was strong enough to carry the load of the pendulum impact without visible damage. Due to the limited energy absorbtion of the PP parts, the bumper skin and the absorber, which was placed on the aluminium bumper beam, were completely compacted, in case of the offset pendulum impact, resulting in high local strains and the risk of plastic deformations (stress whitening). In case of the frontal pendulum impact only some stress whitening around the license plate is to be expected, which could be solved by increasing the radius of the corners in this area or by the use of special flexible paint which could help to mask these locally damaged areas. This means that the pendulum impact loading puts high demands on the material properties if the bumper is designed to be flexible enough for pedestrian protection. To tackle this issue DSM conducted extensive materials research to determine the most appropriate grade of PolyPropelene to satisfy the material requirements of a traditional bumper panel and one flexible enough for use in pedestrian impact protection.

Vibration FE analyses with I-deas Master Series were performed in addition to the impact simulations.

Under this loading the grill area was found to be the most flexible. By adding reinforcements in this area the first resonant frequency value was raised for the bumper system above the vibration frequencies of the engine, without influencing the other load cases.

Figure 18. Ecofront demonstrator

CONCLUSIONS

As part of a complete vehicle concept development project a vehicle front called 'Ecofront' was developed with the aim to decrease its mass while improving the crash performance. Frontal impact protection [6] and pedestrian safety were considered. The part of the project which refers to the pedestrian safety aspects was described in this paper. The demanding new EEVC WG17 requirements for pedestrian protection were used to design the Ecofront, which also included styling and packaging requirements (fig.19). With computer simulations the feasibility of the newly developed design concepts were shown. Computer simulation models were validated with component testing.

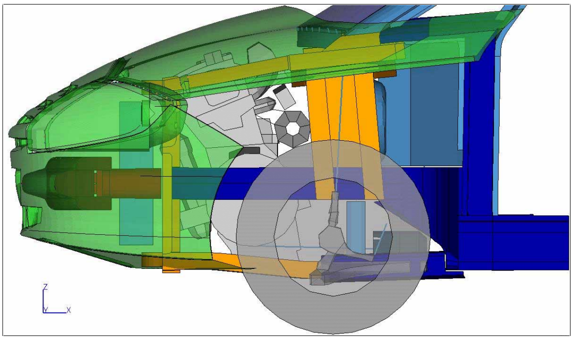

Figure 19. Package of the Ecofront

This project showed that the geometrical shape of the exterior, the vehicle style, and the package design are very important for meeting the design targets. This means that pedestrian safety has to be considered in an early stage in the styling and package design of a vehicle.

For the bonnet a two layer and a multi layer construction was developed. HIC values below 1000 can be achieved by tuning the offset of the underlayer (BMC) dependant on the amount of curvature in the panel. Looking at the shape of the deceleration curves in case of a head impact, the expected “ideal” shape is not completely achieved by choosing special material properties only. An ideal HIC deceleration curve can only be achieved through a combination of material properties and certain global geometrical shapes. However styling features that result in high local stiffnesses should be avoided. An example regarding the transition between bonnet centre and fender area was discussed in this paper.

For leg impact it is important to achieve a proper balance in stiffness between bonnet leading edge, bumper and spoiler. Stiffness characteristics of the different parts were obtained from conceptual optimisation studies. These characteristics were translated into a pedestrian friendly bumper. FE simulations show that the bumper satifies the requirements of EEVC WG 17. Physical testing for validation of the bumper is planned.

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