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REDISIGN OF A FRONT BONNET TARGETTED TO LIGHTWEIGHT AND PEDESTRIAN SAFETY BY VIRTUAL TECHNIQUES

Scattina A.[1], Gaviglio I.[1], Belingardi G.[1], Chiandussi G.[1], Gobetto E.[2]
[1] Department of Mechanics, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
[2] E&D – Advanced Engineering, Fiat Group Automobiles S.p.A., Corso Settembrini 40, 10135 Torino, Italy

Abstract: *The use of innovative virtual test procedures is ever more important. They allow to reduce the development time and to pursue several targets at the same time. In design for active and passive safety¸ they are very useful in order to forecast the impact behaviour of car structures without making use of expensive prototypes and, at the same time, to reduce as much as possible the weight of the component/system with a consequent reduction in fuel consumption and carbon dioxide emission.*

Once excellent results in terms of active and passive safety have been obtained, the attention of car manufacturers and of the public opinion has been focused on the safety of the vulnerable road users (VRU), pedestrians and cyclists. Some examples concerning the redesign of a bonnet with the double target of weight reduction and pedestrian safety will be illustrated. Hybrid metal/plastic and more usual metal sheet solutions have been compared. The static performance (stiffness and denting resistance) as well as the impact against a pedestrian head have been evaluated by means of FEM models along with actual regulations.

The design process of the bonnet in case of pedestrian head impact has been investigated also by using a head model in order to introduce and evaluate the possible advantages of the introduction of human models in the design process.

Keywords: pedestrian safety, lightweight bonnet, FEM analysis

INTRODUCTION

Vehicles are an important source of pollution [1,2]. Between the different sources of pollution, nowadays the attention has been focused on the production of carbon dioxide (CO2), a greenhouse gas widely granted for the climatic change of the planet. It is a primary product of combustion and, for this reason, its production is directly connected to fuel consumption and, consequently, to vehicle weight [3-7].

Passenger safety in vehicles have become increasingly important [8-12]. In the last years excellent results in terms of occupant protection and active and passive safety have been obtained and nowadays the main attention has been concentrated on the safety of the vulnerable road users, e.g., pedestrians and cyclists [13-16]. The improvement of the passive and active safety of actual vehicles is usually obtained by introducing new electronic and/or mechanical devices and, as a consequence, by increasing the total weight.

It is evident that weight reduction and safety improvement are nowadays two fundamental but opposite tasks in the design process of a new vehicle. Innovative virtual instruments, such as the finite element methodology, have become very important and indispensable design instruments in order to reach a valid design compromise between them. Moreover, they allow to reduce the development time by predicting the structural and impact behaviour without using expensive prototypes.

The example of a bonnet redesign process with the double task of weight reduction and pedestrian safety improvement will be presented. The most important static and dynamic performance will be taken into consideration by means of the finite element methodology by considering the most recent regulations.

PEDESTRIAN HEAD IMPACT REGULATIONS

The passive safety of a vehicle in case of impact against a pedestrian is evaluated by means of specific experimental tests. In particular to evaluate the injury level on a pedestrian head, a specific head form is launched against the bonnet and the windscreen in previously defined impact points. In order to determine the impact points, the bonnet and windscreen are divided in sectors as shown in figure 1. The position of the sector boundaries are defined in detail by the regulations considered. The first area (red line in figure 1) concerns an impact against a child head, while the upper area (blue line in figure 1) concerns the impact against an adult head.

The head form used to simulate the pedestrian head is usually made by an aluminium semi sphere covered by a silicon rubber skin. The semi sphere is closed by a metal or plastic plate. An accelerometer is positioned in the centre of gravity of the head form. The dimension and the weight of the head form vary depending on the regulation adopted and on the pedestrian age, an adult or a child [17-19]. For the following analyses, the ACEA phase II regulations have been considered. In this case, the external diameter of the child head semi sphere is 130 mm and its weight is 2.5 kg, while the diameter of the adult head form is 165 mm and its weight is 3.5 kg. Also the speed and the angle of impact are defined by regulation. According to these rules the impact speed is 40 km/h and the impact angle is 50° for the child head and is 65° for the adult head.

The injury level on the pedestrian head is measured by mean of the head injury criterion (HIC). It is evaluated integrating the acceleration of the head form centre of gravity as follow:

$$HIC_{\max} = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) \right]^{2.5} (t_2 - t_1) \right\} \qquad (1)$$

In this work the HIC15 has been considered characterized by a time duration of mobile windows used during integration of 15 seconds. The upper limit value of HIC_{15} imposed by the ACEA phase II regulation is 1000.

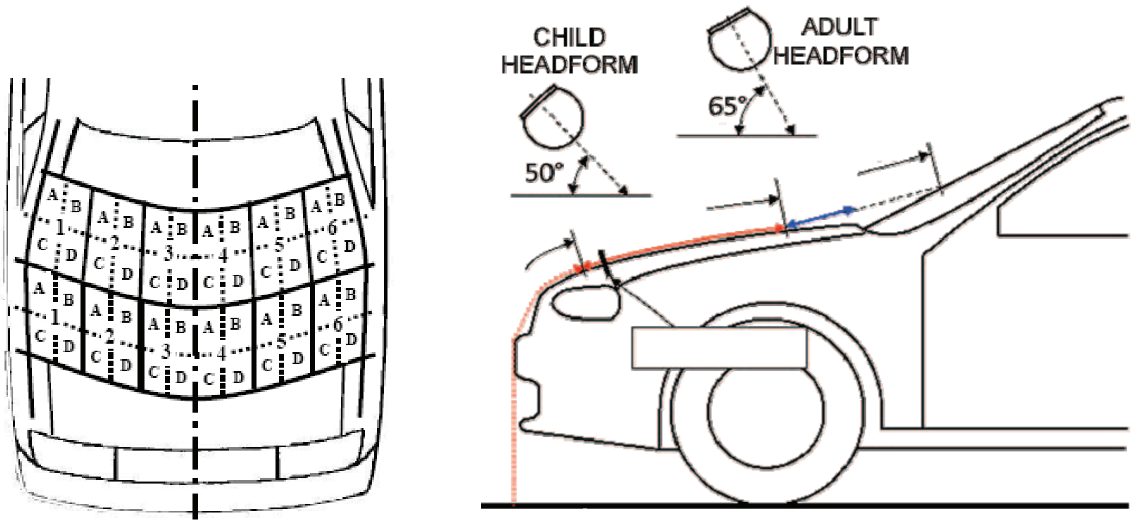


Fig. 1. Subdivision of bonnet and windscreen surface for the choice of impact points (on the left) and pedestrian head impact test configuration (on the right)

HYBRID BONNET FOR MEDIUM/LOW SEGMENT CAR

The results of the redesign process of a bonnet of a middle/low segment car are presented. The main targets of the redesign process have been the weight reduction and the improvement of the passive safety in the case of impact against a young pedestrian.

First numerical simulations have been done on a reference model (figure 2) to evaluate the correlation of the numerical model with the experimental results. Figure 3 shows the comparison of experimental and numerical results in terms of acceleration recorded on the centre of gravity of the head form as a function of the time. The correlation obtained has been very good.

Starting from the validated reference model, a hybrid structure made of a thermoplastic internal structure and a metal external skin has been considered. The thermoplastic material allows to reduce the pedestrian head injury level by reducing at the same time the weight of the structure, whereas the metal skin allows to meet the imposed quality requirements. The shape of the external skin has not been modified due to style constraints, but material modifications have been taken into account.
Two specific geometries (G1 and G2 in figure 4) have been initially defined. The same steel used for the reference solution has been chosen for the external metal skin, while a long glass fibre reinforced polyamide has been implemented for the thermoplastic internal structure. This material has been chosen for its better thermal properties if compared to that of a polypropylene. The analyses of pedestrian head impacts carried out on these entry solutions show that the proposed design solutions are too stiff. In fact, the HIC values are too large to be accepted (figure 5).

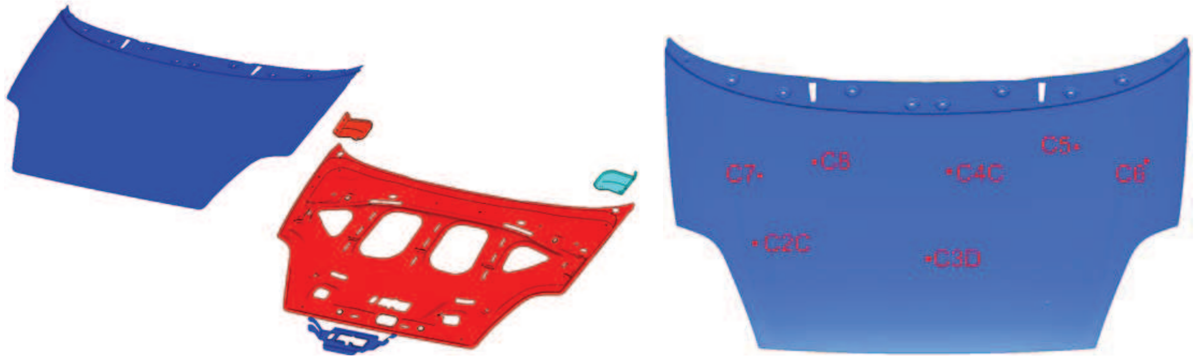


Fig. 2. On the left, the reference bonnet solution made of stamped steel parts, on the right the arrangement of impact poitns

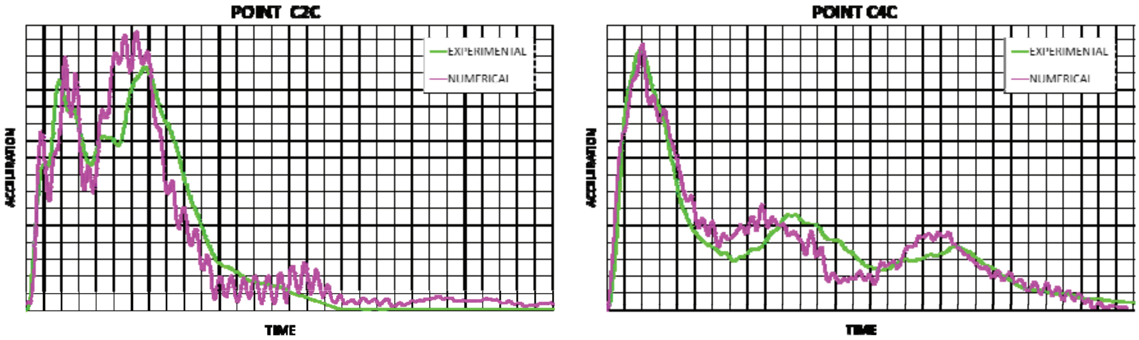


Figure 3. Comparison between experimental and numerical acceleration curves for two different impact points

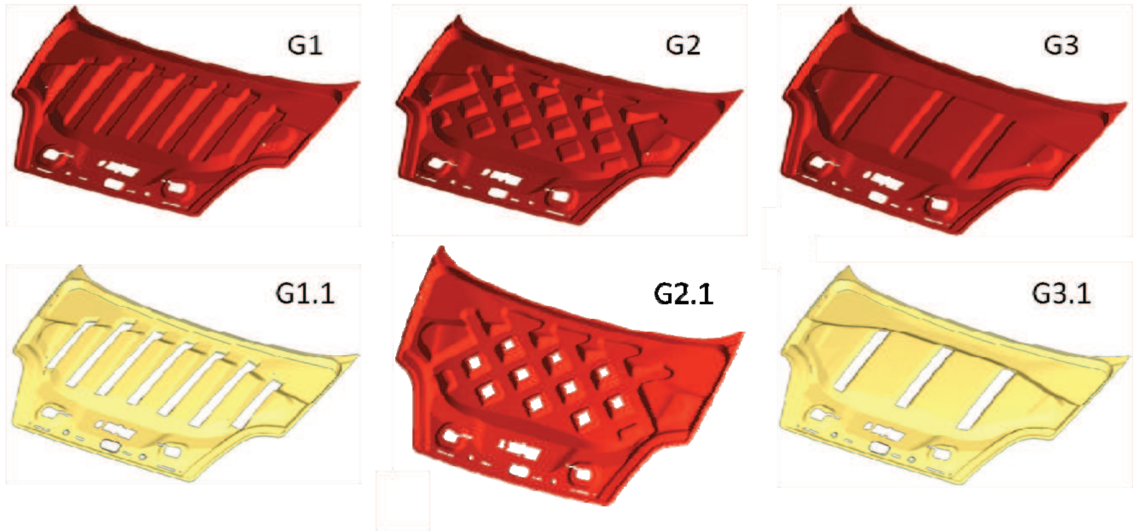


Fig. 4. Different types of inner structure studied during the work

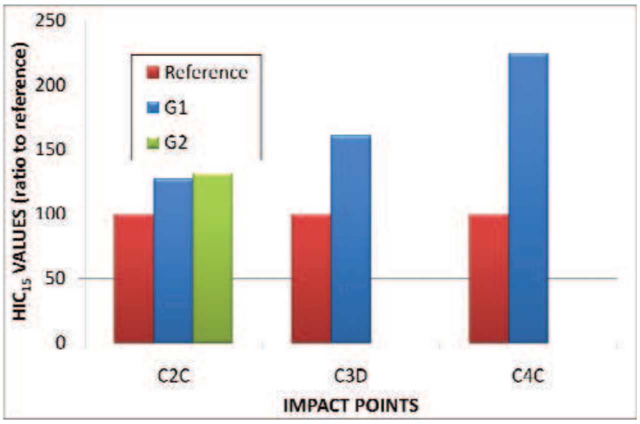


Fig. 5. Pedestrian head impact simulation results

Several modifications have been implemented in order to meet the regulations. In particular, the geometry of the internal structure has been modified as shown in G3 (figure 4). It is characterized by a smaller number of longitudinal ribs with a smaller depth if compared with those of the G1 design. A series of cuts to reduce the weight and to reduce the stiffness has been applied on the first three geometries proposed (G1.1, G2.1, G3.1 in figure 3). The external skin has been made of aluminium (6xxx series) and the material of the internal structure has been modified by introducing a polyamide with short glass fibres. All the proposed solutions have been analyzed by evaluating the pedestrian head impact performance and the torsional stiffness (figure 6).

The most promising solutions (G1, G3, G3.1) have been then analyzed in detail. In particular for sake of pedestrian safety, the behaviour of the bonnets has been examined in some additional impact points, while for sake of the static tasks, the torsional stiffness, the side stiffness and the denting resistance have been evaluated by means of non linear analyses (figure 7).

The best solution identified is characterized by an external skin made an aluminium 6xxx series and by a polyamide short glass fibre reinforced internal structure with the design G3 of figure 4. This solution offers a pedestrian safety performance comparable with a full aluminium solution, a state-of-the-art for the bonnet aimed to pedestrian safety.

Some additional studies have been carried out by considering a peripherical geometry obtained by simply erasing the central part of the internal structure of the reference solution (figure 8) and by implementing a whole aluminium bonnet. In this further activity only the pedestrian safety performance has been considered. The HIC15 values evaluated in head impact analyses have been compared with those previously obtained. The comparison puts in evidence that the use of aluminium with a peripherical inner structure has to be considered as the best solution for weight reduction and pedestrian safety targets.

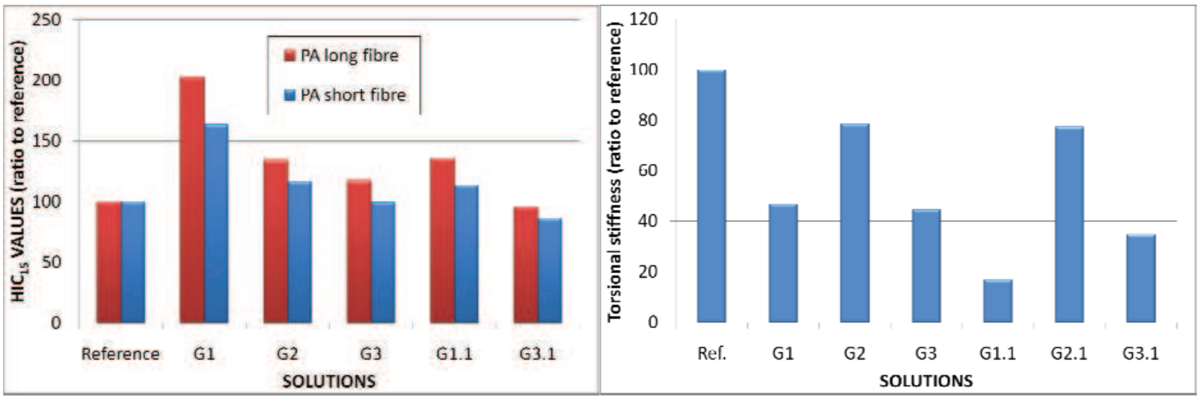


Fig. 6. HIC$_{15}$ values in pedestrian head impact simultaions (left) and bonnet torsional stiffness (right)

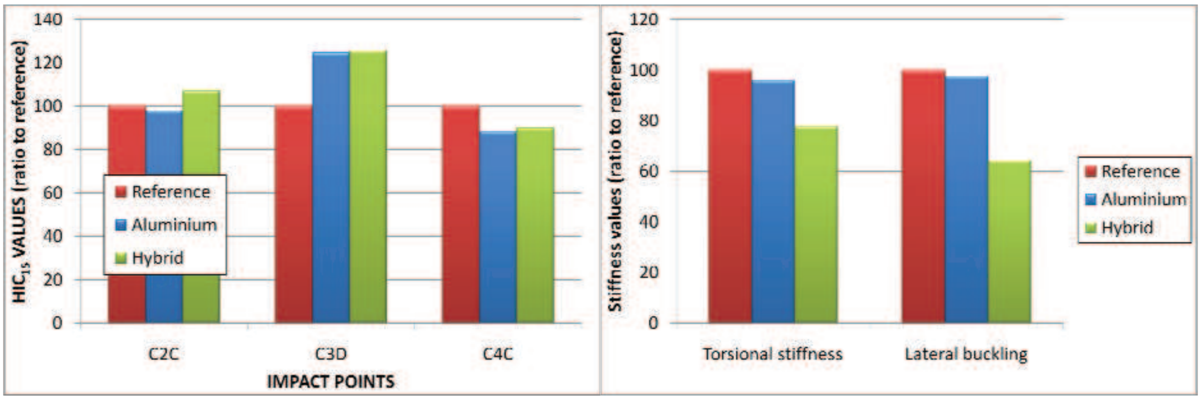


Fig. 7. HIC$_{15}$ values in pedestrian head impact simultaions (left) and bonnet torsional stiffness (right)

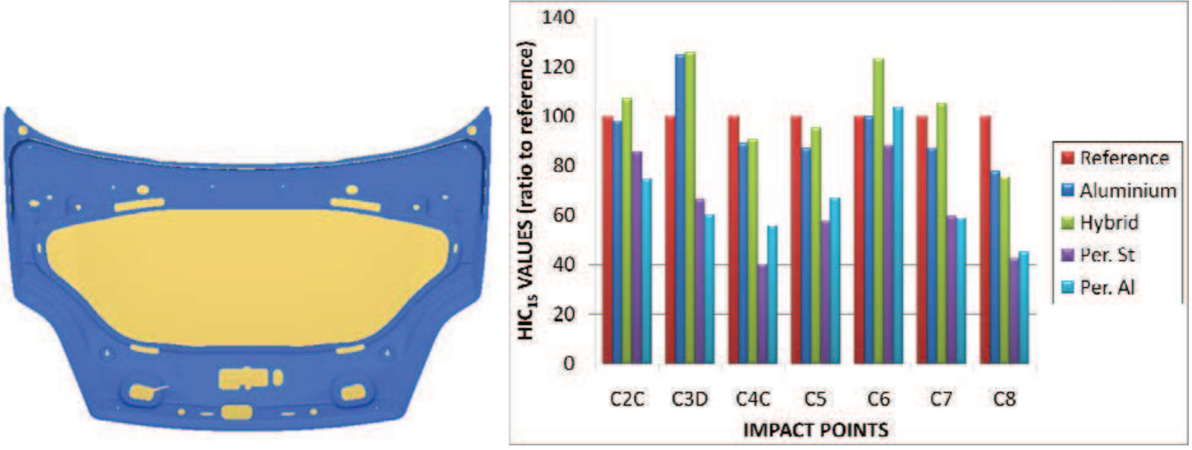


Fig. 8. Peripherical solution for the reference bonnet (left) and pedestrian head impact simulation results for different solutions (right)

A further hybrid metal/plastic bonnet design with a net internal structure has been studied. This design solution joins the advantages of the void internal structure with a further weight reduction and a better distribution of the energy generated during the impact between the pedestrian head and the bonnet and a consequent reduction of the head injury levels. This design solution is shown in figure 9. It is characterized by an external aluminium skin, a void internal structure in aluminium and a net wire design made in polyamide reinforced with glass fibres.

This solution can be considered a concept design. It allows to obtain a further weight reduction (50% less than the reference solution) and a reduction of the HIC15 value (figure 9) of about 40% in average. The torsional stiffness is lower than that of the reference design solution but acceptable if compared to the design requirements.

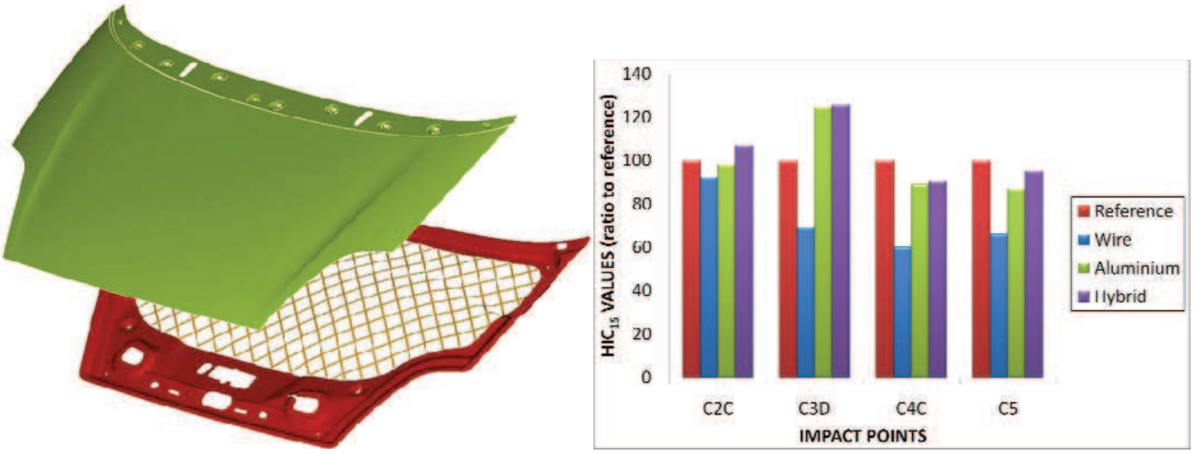


Fig. 9. The net wire hybrid concept bonnet (left) and the HIC$_{15}$ evaluated in the pedestrian head impact simulations

HYBRID BONNET FOR LIGHT COMMERCIAL VEHICLE

The results of a redesign process for a bonnet of a light commercial vehicle are also described. The main tasks of the redesign activity are weight reduction and, for the first time for this type of vehicle, passive safety improvement in impacts against VRU.

The reference bonnet taken into consideration is shown in figure 10. It is characterized by an external skin, an internal structure and an air intake fixed between them. The air intake system is aimed to bring air to a lower conveyor and to the air conditioning system for the cockpit.

A hybrid metal/plastic bonnet with a metal external skin and a thermoplastic internal structure has been designed. The use of a thermoplastic material for the internal structure allows to integrate the air intake in the design of the internal structure. Also in this case, the main engineering performance considered during the redesign process have been the torsional and side stiffnesses, the denting resistance and the pedestrian head injuries.

The development process has started with the simulation of the pedestrian head impact on the reference design solution in order to understand its performance. The results obtained in three different impact points (figure 11) have not been very satisfactory due to the large HIC15 values.

A new design for the hybrid bonnet has been proposed as shown in figure 12. The thermoplastic internal structure is characterized by a flat sheet with the upper part of the air intake integrated in it. The design is symmetric because both the left hand and the right hand drive version have been considered in a single piece. The air intake has been completed by adding a lower panel connected by means of an adhesive. The external skin has been kept with the same shape of the reference solution. The external panel is made of aluminium of 6xxx series, while two different materials have been taken into consideration for the internal thermoplastic structure, a polypropylene and a polyamide both reinforced with glass fibres. Polyamide offers better mechanical and thermal properties while the polypropylene is cheaper. Polyamide structures can be painted on line during the production process whereas polypropylene structures require specific offline painting processes. Both the solutions have been developed in parallel.

Fig. 10. An exploded view of the reference bonnet solution of a light commercial vehicle (on the left) and a photograph with a front view of the opened bonnet (on the right)

A simulation test concerning the pedestrian head impact, the torsional stiffness and the denting resistance have been carried out. The results obtained (figure 13) have been quite interesting and encouraging. The design solution characterized by an internal structure in polyamide offers better torsional stiffness but worse pedestrian safety performance due to its mechanical properties. Opposite results have been obtained by using the polypropylene. In fact the head impact simulations have shown ruptures in the impact points. Some modifications have been evaluated: the introduction of several ribs and the local modification of the thickness of the internal structure (shown in figure 12 in purple) to improve the denting resistance and the global stiffness, the introduction of several material discontinuities in order to decrease the weight. The final design for the inner structure is shown in figure 14.

Both the solutions developed have been prototyped in order to carry out some experimental tests (figure 15).

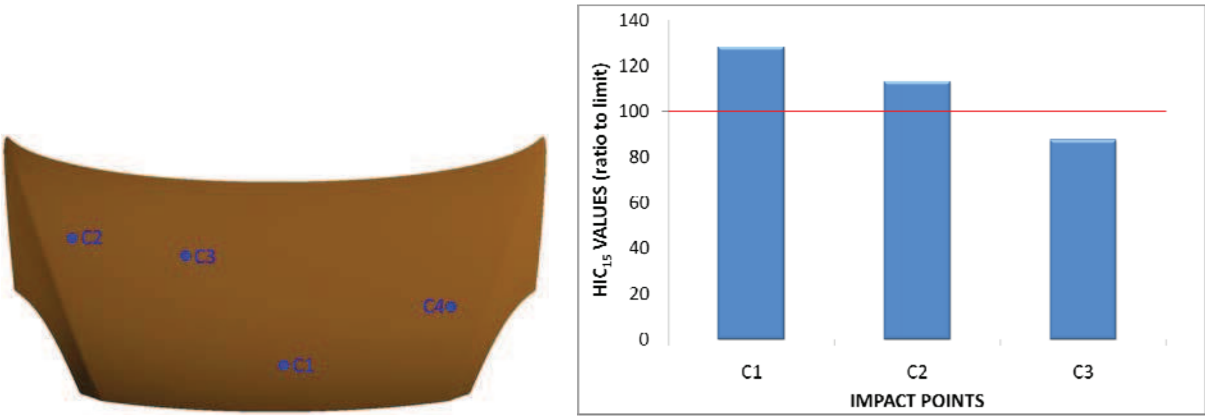


Fig. 11. Arrangement of the impact points on the bonnet surface (on the left) pedestrian head impact simulation results for the refernce solution (on the right). The red line represents the HIC_{15} limit value

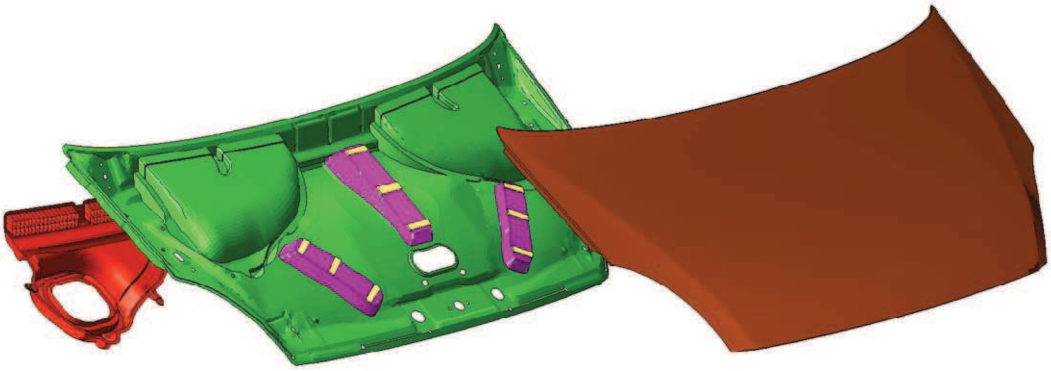


Fig. 12. An exploded view of the first design for the hybrid bonnet

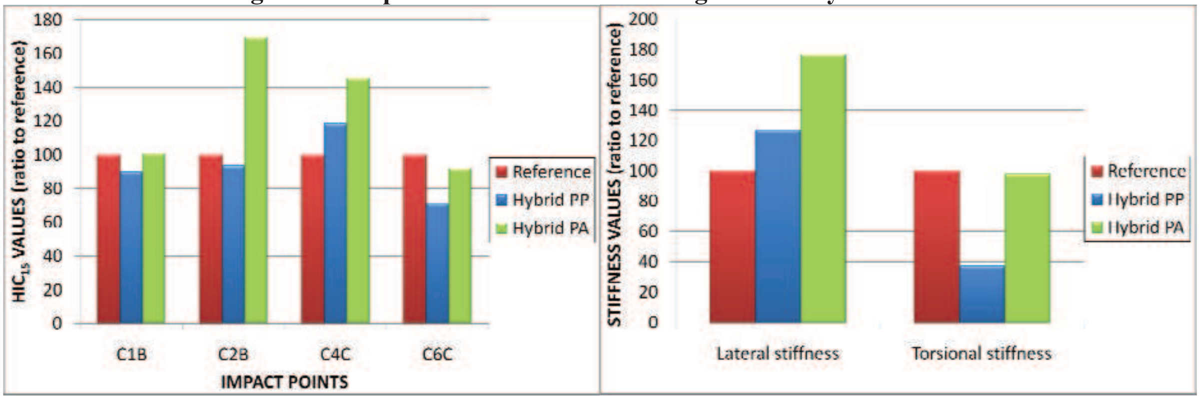


Fig. 13: on the left pedestrian head impact simultaion results; on the right torsional stiffness results for the fisrt hybrid solutions

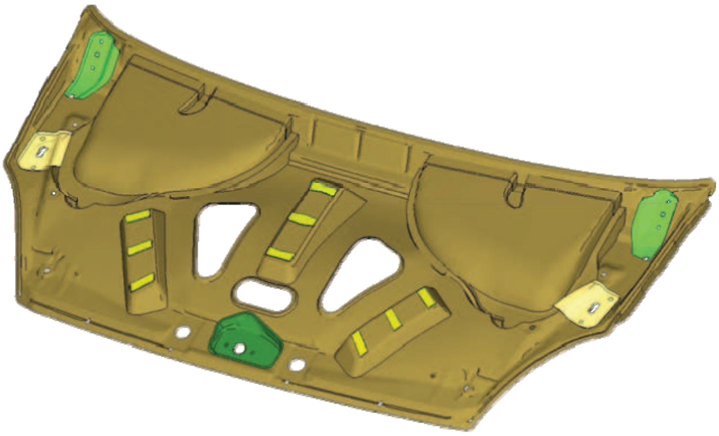


Fig. 14. The final design for the thermoplastic inner structure

Fig. 15. the prototyped inner structure

BONNET DEVELOPMENT/DESIGN WITH HUMAN HEAD MODEL

The evaluation and the improvement of the bonnet behaviour against vulnerable road user impact can be carried out in a virtual environment by introducing a full FE head model instead of a simple headform impactor. The substitution of the headform with a complete FE element model allows to overcome the intrinsic limits of the HIC parameter in the evaluation of the head injury level.
The head model, fully developed at the Department of Mechanical Engineering of the Politecnico di Torino, has been built starting from CT scans and MRI images and is characterized by the presence of the following components:

- an external layer of brick elements to represent the scalp,
- three layers of eight node brick elements (two external layers of compact bone and one internal layer of cancellous bone) to represent the cranial bones,
- shell elements with only inertial properties to describe the facial bones,
- four nodes shell elements to describe the dura mater, the falx and the tentorium membranes,
- eight node brick elements to describe the CSF,
- tetrahedral elements to model the brain tissues,
- tetrahedral elements to model the ventricles.

The overall model is composed of 55264 elements and about 26000 nodes and is represented on figure 16.

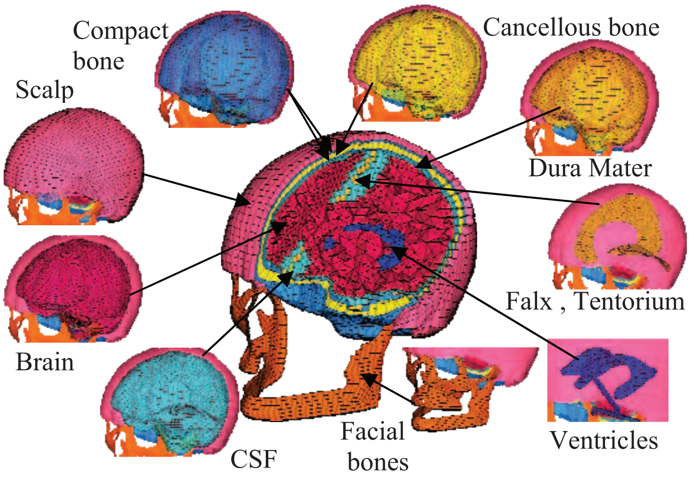


Fig. 16. Finite element head model

The mechanical properties of the different tissues have been chosen taking advantage of literature data (tissue experimental test or similar head models). The model has been validated by simulating the experimental test on corpse found on literature and by comparing the numerical and the experimental results.

The impact between the FE head model and a generic car model has been simulated as represented on figure 17. Impact conditions have been changed from prescribed regulation on different simulations by varying the impact angle (a), the impact speed (V) and the point of impact on the head (d).

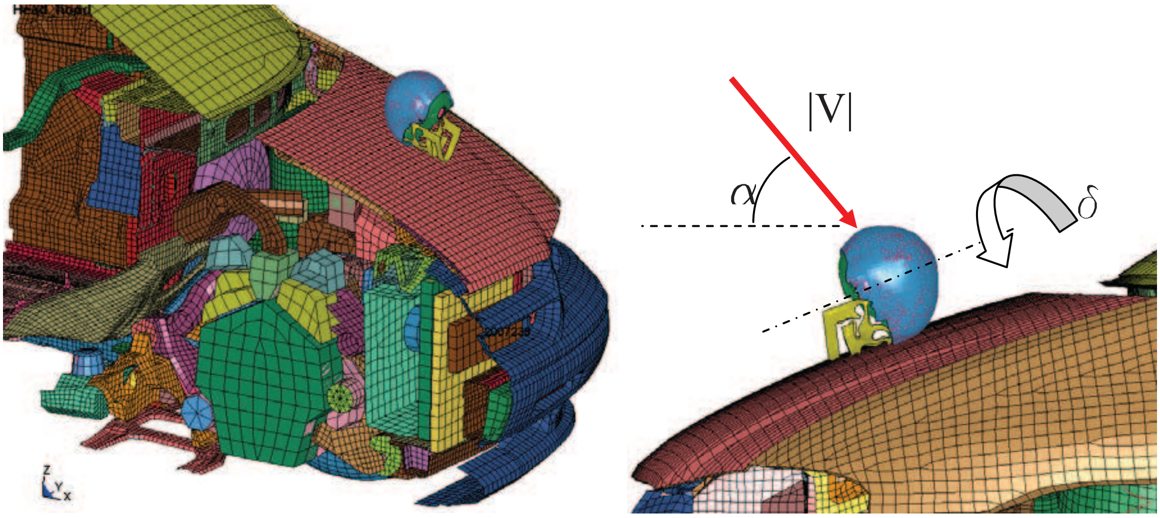
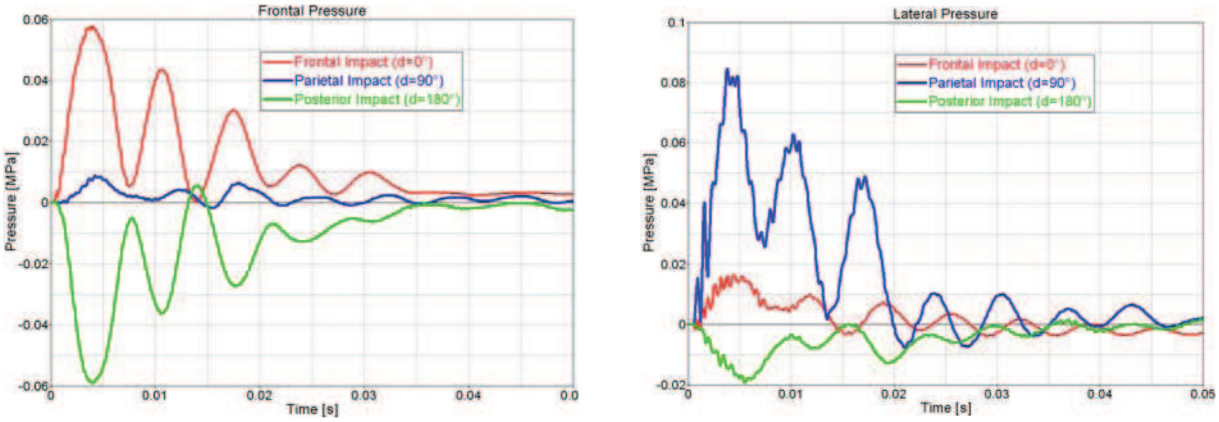


Figure 17. Head model impact condition against hood.

Fig. 17. Head model impact condition against hood

By using a full FE head model it is possible to evaluate a realistic head behaviour and to take into account several kind of injuries for different tissues and in different impact conditions. It is not necessary to pass through physical measures (i.e. headform acceleration) to obtain injury parameters (i.e. HIC) but it is possible to evaluate injuries directly by model results as internal pressure distribution or element fractures. The intracranial pressure behaviour in some areas during different impact conditions has been represented on figure 18 and 19.



Frontal Pressure

Left Temporal Pressure

Fig. 18. Brain pressure on different zones. Test condition: a=50°, |V|=11.1 m/s, different d

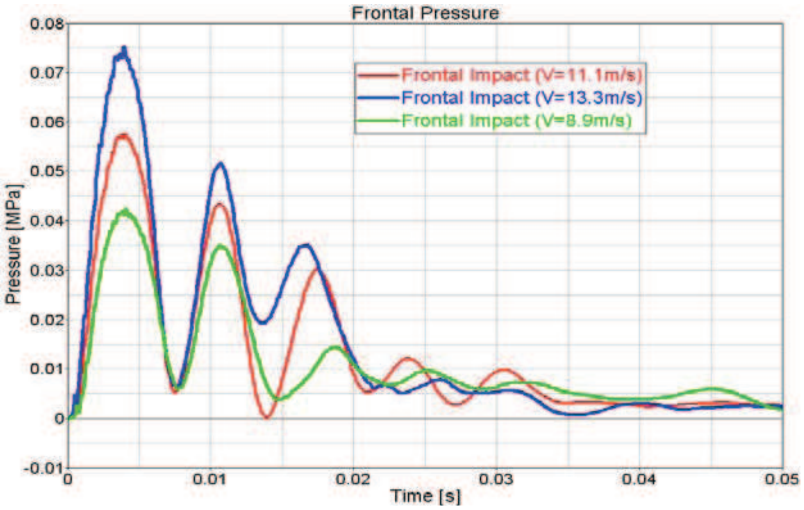


Figure 19. Brain pressure on frontal impact zone. Test condition: a=50°, d=0°, different |V|

CONCLUSIONS

The design process of specific automotive subsystems is always more complex due to the increasing requirements. By taking into consideration the bonnets of a medium/low level car and of a light commercial vehicle, the search for an optimal compromise between weight reduction and passive safety improvement in car-vulnerable road user impacts has been searched for. The use of virtual instruments like the finite element method allowed to verify several different design solution in a short time allowing for the identification of the best compromise. Hybrid metal/plastic and more usual metal sheet design solutions have been compared showing that innovative materials can be introduced with successful results in terms of weight reduction and injury level reduction on the pedestrian head.
The dynamic behaviour of the bonnets has also been investigated by introducing a full FE head model. The FE head model has been used instead of the head form required by actual regulations allowing for a direct and immediate evaluation of the biological damages on the human head system due to the impact against the bonnet.

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