DEVELOPMENT OF AN HYBRID HOOD TO IMPROVE PEDESTRIAN SAFETY IN CASE OF VEHICLE IMPACT

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ABSTRACT

In recent years car manufacturers when developing new car designs have paid great attention to two main aspects. On one hand there are the pollutant emissions and in particular the carbon dioxide emissions which are directly connected to the fuel consumption of cars, on the other hand there is the always increasing safety level required for the cars, with a particular attention to the safety of pedestrian and other vulnerable road users (VRU).
The present paper reports some results of a recent research activity developed in this perspective and specifically devoted to the design of a bonnet for a middle/low segment car. A global overview on the different solutions which can be used to obtain a lightweight and pedestrian safe bonnet will be illustrated.
The main part of the work deals with the design of a hybrid metal/plastic bonnet. All the aspects examined during the design of a new bonnet will be taken into consideration, starting from the technical performance and going through the manufacturing and economical aspects.
Then some considerations on a bonnet with a peripherical frame solution will be presented. At the end, the study on a further concept of hybrid bonnet characterized by a particular wire design of the inner structure will be addressed.

INTRODUCTION

In the recent years substantially two main objectives are put in evidence as the main targets in the automotive design. On one hand cars are one of the most important sources of pollution. There are different reasons to explain why vehicles are a source of pollution [1-4], first of all there are the products of engine combustion, the primary ones, the carbon dioxide (CO_2) and the secondary ones, such as carbon monoxide (CO), oxides of nitrogen (NO_x) and unburned hydrocarbons (HC). Then the cars are also an important source of noise pollution [5], and at last but not least, the vehicles have to be considered as a solid pollution at the end of their life. Among these types of pollution, in the recent years the pollution due to the emission of carbon dioxide is certainly considered the most important one, because it is a green house gas and is considered responsible for the planet climatic changes. In particular, as it is possible to see in Figure 1, if in the last years the emissions of carbon dioxide from different sectors have decreased, the contribution from the transport sectors has continuously grown [1].

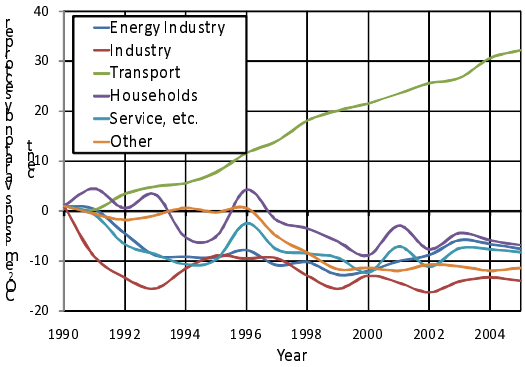

Figure 1. Variation of the global CO_2 emissions by sectors as a function of the years.

In this field, from many years a series of regulations have been proposed and emitted by different source such as the national Governments but also by association of car manufacturers, with the scope of a relevant reduction of the production and the emission of carbon dioxide. In order to face this more and more strict limits, the car manufacturers are currently engaged to improve the global efficiency of the vehicles, working on different aspects: engine, transmission and aerodynamics efficiency. However, in order to

meet the targets, one of the most important aspects is the lightweight, in fact the production of carbon dioxide is directly related to the fuel consumption and therefore to the weight of cars.
The other main subject in the automotive design is the safety. In recent years many improvements have been achieved in the field of safety for the occupants of the vehicles, by working both on active and passive safety. Nowadays the attention of the public opinion and of the car manufactures is focused on the safety of the vulnerable road users (pedestrians and cyclists), in fact the number of dead and injuries due to road accidents that involve these categories is very important [3,9,11]. Also in this field more and more strict regulations have been proposed, not only by the national Governments but also by rating institutes such as the Euro NCAP [12]. A series of impact tests have been introduced which replicate possible accident involving a pedestrian, and a series of target have been established which have to be reached to get the approval for the vehicle [10, 16, 17]. Since 2009 the total score obtained in the rating tests includes the score referred to pedestrian protection; it is unnecessary to remind here how Euro NCAP score is considered now a marketing key for the car manufacturers.
In this perspective it is possible to collocate the present research work, made in collaboration between Fiat Research Centre and Politecnico di Torino, aimed to the development of a hybrid metal/plastic bonnet for a car of medium/low segment. The progressive development of the bonnet design, starting from a reference solution, will be illustrated. The main targets of the work have been a weight reduction of about 30% in comparison with the reference bonnet, together with a reduction of the injuries to the pedestrian head in case of impact. Further the final solution should have competitive total industrial cost when compared to a full aluminium solution, and to ensure the same quality and functionality of the reference solution. The development has started from a predefined hybrid concepts, but different solutions in terms of shapes and materials have been considered. During the development the main stream has been focused on the technical performance, but also manufacturing considerations such as the compatibility with the current assembly line and some economical aspects have been taken into account. All the development phase has been done by means of virtual simulations, in particular using the finite element model technique.
At the end also some considerations on alternative solutions made by a peripherical reinforcement as bonnet frame will be illustrated together with a further hybrid bonnet concept with a particular wire design for the inner structure.
The reference bonnet is shown in an exploded view in Figure 2, it is completely made by stamped steel sheet parts and it is composed by an outside panel, which will be considered constrained by the aesthetic style of the car (for this reason its shape cannot be changed but it is only possible to modify the sheet thickness and the material), by an inner structure aimed to structural functions, and by a series of reinforcements applied near the hinges and above the locking mechanism.

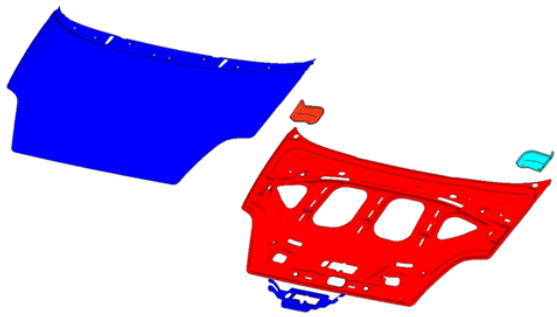

Figure 2. An exploded view of the reference bonnet.

HYBRID BONNET

The main hybrid concept has been defined starting from the experiences made in other similar activities [6-8], in particular focused on a tailgate. This concept is characterized by a thermoplastic inner structure, in order to exploit the potentials of this material in terms of freedom in shape and thickness distribution, and by an outside metal panel in order to meet the quality requirements. Starting from these concepts, and on the basis of information obtained in a preliminary benchmarking activity, where the geometries and the materials used for a series of bonnets currently in production have been investigated, some initial ideas for the hybrid bonnet have been proposed. In particular the design of the inner thermoplastic structure has been considered. The first solution consists of a simple perimeter structure, the other ones are characterized by a perimeter structure with a series of longitudinal and crossed ribs. These initial concepts are shown in Figure 3.

As the main targets of this work is lightweight together with reduction of injury risks for the impacted pedestrian head, the different proposed solutions have been evaluated first under the pedestrian safety point of view, then the most promising ones have been evaluated also versus other structural performance: stiffness and l denting resistance

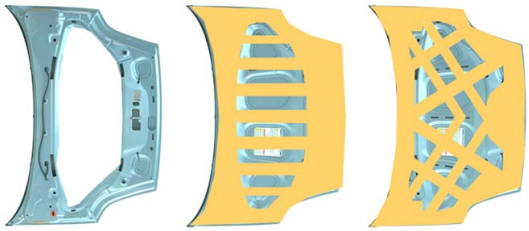

Figure 3. Three main preliminary concepts for the inner structure of hybrid bonnet.

For what concerns the pedestrian head impact tests, simulations have been performed according the ACEA phase II regulations. The test parameters have been an impact speed of 40 km/h with an impact angle of 50°.
Before to examine the first proposed solutions, the quality of the prepared FEM model has been assessed by comparing the numerical results of some pedestrian head impact tests with the available experimental values. In particular three different impact points, namely C2C, C3D and C4C, (their positions on the bonnet surface are shown in Figure 4) have been examined for the reference bonnet solution. For this work the well known software LS-Dyna®, that is based on a step by step explicit integration scheme, has been used. The results have been examined in terms of HIC_{15} and acceleration curves recorded during the test execution in the head form centre of gravity.
The diagrams shown from Figure 5 to Figure 7 establish a systematic comparison between the experimental and numerical acceleration curves, while and the HIC_{15} values are reported and compared in Table 1. The results of this quality assessment are very good, not only because the numerical values of HIC_{15} are very close to the experimental one but also because all the acceleration curves have remarkable accordance both in values and in trend with the experimental ones. It has been possible to conclude that this model can be used for the following development of the hybrid hood because it has simulated very well the real behaviour.

Table 1.
Comparison between the numerical and experimental HIC_{15} results for the reference solution

	HIC_{15}	
Points	Experimental	Numerical
C2C	1852	1912
C3D	1181	1381
C4C	943	945

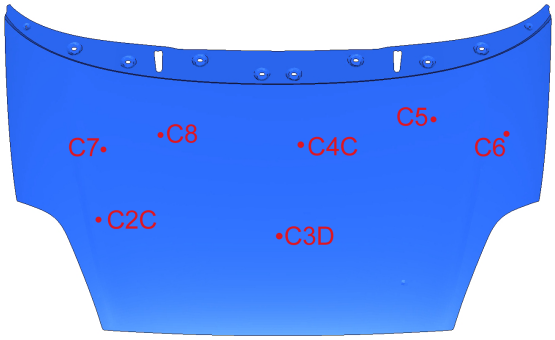

Figure 4. Position of the impact points on the bonnet surface.

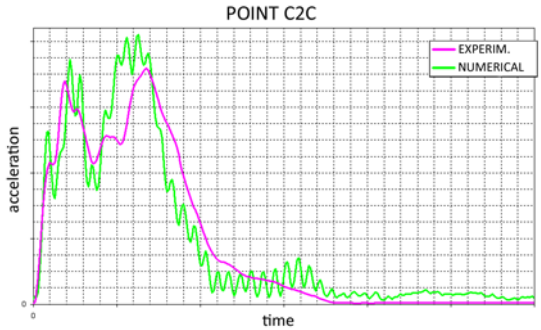

Figure 5. Comparison between the experimental and numerical acceleration curves for the point C2C.

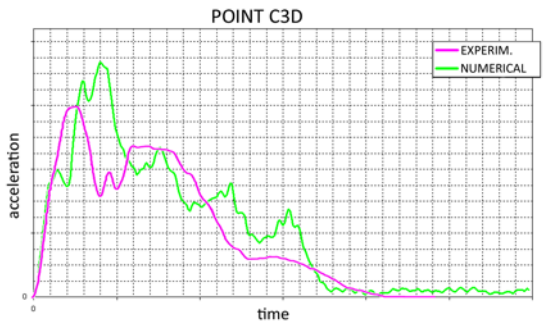

Figure 6. Comparison between the experimental and numerical acceleration curves for the point C3D.

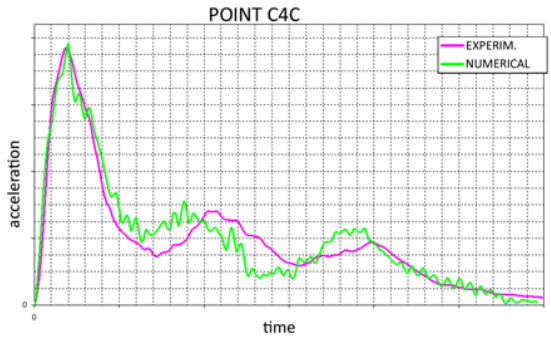

Figure 7. Comparison between the experimental and numerical acceleration curves for the point C4C.

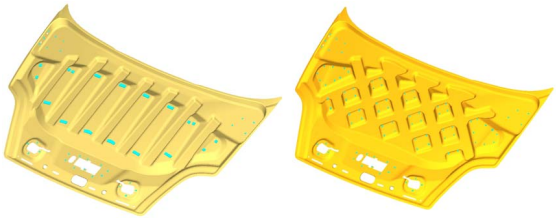

Figure 8. Two different designs for the inner structure, G1 on the left, G2 on the right.

At this stage the design of the hybrid bonnet has begun and some solutions for the thermoplastic inner structure have been drawn, according to the information obtained in the first preliminary benchmarking phase. In particular, as shown in Figure 8, two different solutions have been proposed, namely the G1 and the G2.
The G1 solution is characterized by a series of longitudinal ribs, while the G2 solution has a series of cross ribs. For what concerns the material to be adopted for this part, the thermosetting materials have been discarded, because they cannot be recycled in an easy way. An interesting solution for the material, both from lightweight and cost point of view, could be the polypropylene, which is one of the most used thermoplastic material for automotive applications, but this material can have problems with the temperature due to the proximity of the engine. For this reason it is necessary to consider a material with better thermal and mechanical properties, and in this case a polyamide reinforced by glass fibres has been chosen. In particular, in a first development, a long glass fibre reinforcement with a weight fraction of 40% has been selected. The main mechanical properties of this material are: tensile modulus of 9300 MP and tensile strength of 146 MPa. For what concerns the thickness of the inner structure, initially two different values have been considered, in particular 2.5 and 1.2 mm but the second one has been immediately discarded because, from the manufacturing point of view, is not feasible. The plastic material has been modelled using the card *MAT_PIECEWISE_LINEAR_PLASTICITY. The stress-strain curve of the material has been supplied at room temperature. The design of the hybrid bonnet has been completed by the same parts of the reference solution: an outside steel skin and a series of steel reinforcements. The join between the different parts has been made by structural adhesive bonding.
The pedestrian safety performance of this first hybrid bonnet has been evaluated in the same impact points considered up to now. The obtained results are shown in Table 2 in term of HIC_{15}.

Table 2
HIC_{15} results for the first hybrid bonnets

HIC_{15}	Impact point		
Solution	*C2C*	*C3D*	*C4C*
Reference	1912	1385	941
G1 Th. 2.5	2429	2222	2112
G1 Th. 1.2	2027	1507	1016
G2 Th. 2.5	2515	-	-
G2 Th. 1.2	1966	-	-

The obtained value are generally too high, and by examining also the acceleration curves which have led to these results, it has been possible to conclude that these first solutions for the hybrid bonnet have resulted too stiff for this type of performance. For this reason a series of corrective modifications have been introduced.
First of all a third design for the thermoplastic inner structure, as shown in Figure 9 and called G3, has been proposed. This solution is made once again by longitudinal ribs but in a lower number and with a lower height in order to reduce bending stiffness. Then, on the three considered inner structures, a series of cuts have been applied in order to reduce further both the weight and the bending stiffness. The new obtained solutions, identified by the extension .1 are shown again in Figure 9. For what concerns the materials, for the inner structure, it has been decided to reduce the mechanical properties of the fibre reinforced polyamide by using a short glass fibre reinforcements, with the same weight fraction, while for the outside panel it has been decided to evaluate the behaviour of different types

of aluminium alloys, series 6xxx, varying at the same time, the panel thickness.
The behaviour of these modifications has been evaluated initially only for the pedestrian safety performance with a complete test plan on the impact point C4C. Results allow to compare all the possible solutions. A summary the results are shown in Table 3. Substantially, the solutions which have a thermoplastic inner structure reinforced with long glass fibre, have to be discarded because are too stiff, even if the external panel has been made in aluminium. A similar thing can be said also for the solutions characterized by a steel outside panel.
For what concerns the inner structure, the best results have been obtained with the G3 design, but also the results obtained with the design G1.1 and G2 are quite interesting, finally, as it has already seen before, the design G1 appears too stiff.

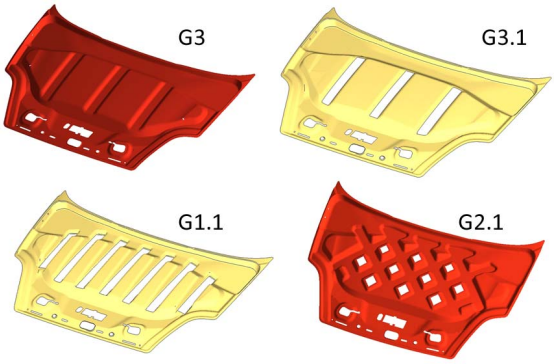

Figure 9. Different considered designs for the thermoplastic inner structure.

Table 3
Comparison of the HIC_{15} results obtained for the different examined solutions.

HIC_{15}	Impact Point C4C					
Solution	*Ref.*	*G1*	*G2*	*G3*	*G1.1*	*G3.1*
Inner Structure: PA long fibre Skin: aluminium	941	1904	1263	1104	1277	902
Inner Structure: PA short fibre Skin: aluminium	941	1540	1097	937	1074	812

On the most promising solutions a further simulation loop has been done, aimed to evaluate the effect of some different types of aluminium alloys and to define the best material and thickness.

At this point of the development it has been necessary to take into consideration a second important performance for the bonnet, the torsional stiffness. This value is obtained with an experimental test after having positioned horizontally the bonnet and by applying a vertical load at one of the two rubber pads, where usually the bonnet is leaned. The vertical displacement of the load application point is measured and then, through a geometric procedure, the applied torque and the related deformation angle are calculated. The ratio between these two values allows to evaluate the torsional stiffness.
Starting from the previous results on pedestrian safety, the bonnet typologies taken into consideration for the torsional stiffness analysis have been designed by an external aluminium skin and an inner structure made by short glass fibre reinforced polyamide. In particular the behaviour of the different design for the inner structure has been investigated. Once again they have been evaluated by means of the results obtained with of finite element simulations. At this stage the scope of these numerical analysis has been to understand the global trend of the different solution taken into consideration. By examining the results collected in Table 4, it is possible to note a deep decrease from the value of reference solution, but it is also necessary to say that this value is much higher than the target. These results have put in evidence as the design G2 is the best solution from the torsional stiffness point of view. The loss in stiffness is also rather low for the cut solution G2.1. The other two solutions G1 and G3 can be considered in target also if the decrease of the stiffness is quite high. Finally the use of cuts in these latter design has been quite relevant because they have caused a dramatic loss in stiffness for the solution G1.1 and G3.1.
Then two different types of lateral stiffness, which are two other important missions usually taken into consideration during the design of a bonnet, have been calculated. In this case the bonnet has been opened at two different angle and a lateral load (in the Y direction) has been applied on the stricker of the lock and then on the mobile hinge. Also in this case the displacement of the load application points has been measured and then the related stiffness has been calculated. The results of these virtual tests have substantially confirmed those obtained for torsional stiffness, for this reason it is possible to make the same considerations mentioned before.

Table 4
Torsional stiffness results for the different design of the inner structure

Torsional stiffness test	
Solution	*Δ stiffness vs reference (%)*
G1	-53.1
G2	-21.4
G3	-55.3
G1.1	-82.9
G2.1	-22.7
G3.1	-65.1

At this point of the development, by integration of the results obtained during the pedestrian head impact test and the stiffness results, it has been possible to define the most promising solution to be investigated in more details. This solution is characterized by an external skin of series 6xxx aluminium, with a defined thickness, and an inner structure, with the G3 design, made with short glass fibre reinforced polyamide, with a thickness of 2.5 mm. By comparison of the weight of this solution with that of the reference one, it is put in evidence a very interesting weight reduction of about 30%. Further this last solution has been examined in more details and, in order to get more information, has been compared with another reference solution made by aluminium. Substantially this second reference bonnet has been obtained simply by substituting the steel with aluminium (series 6xxx for the reinforcements and for the skin, series 5xxx for the inner panel) and appropriately increasing the thickness of the metal sheets. The weight reduction obtained with this aluminium solution has been about 45% once again in comparison with the reference steel bonnet.
First of all a complete analysis has been performed for the pedestrian impact test by simulating the head impact in the first three impact points considered up to now, in the above described impact conditions. The results of these simulations, in terms of HIC_{15}, are shown in Table 5.

Table 5
HIC_{15} results for the most promising hybrid solution compared to the reference ones

HIC_{15}	Impact point		
Solution	*C2C*	*C3D*	*C4C*
Reference	1912	1382	946
Aluminium	1876	1723	837
Hybrid	2048	1739	852

Examining the results it is possible to note that the HIC_{15} values at point C2C are generally not satisfying, This can be explained considering that this point is quite near the perimeter of the bonnet, and in particular near the lamp groups, and for this reason the impact performance are heavily influenced by that near structure. The HIC_{15} values for the lightweight solutions on point C3D are very close, this is due to the low local stiffness of these solutions, as a consequence during the impact the bonnet has reached and hit the lower crossbeam. Point C4C is the more significant for this performance because its behaviour is influenced only by the structure of the bonnet. In this point with the hybrid solutions there is an important reduction of the HIC_{15} value. At this stage of the design development, the three different types of stiffness have been studied for these three solutions. The non linear FE software Abaqus ® has been used. The results for this second type of performance substantially has not evidenced particular problems, the decrease of the stiffness is lower than that assessed during the first analysis, but all the values for the hybrid solution bonnet are completely in target.
The functionality of the bonnet has been further evaluated in term of denting resistance. In this test an increasing load is applied on determined points of the bonnet (usually on the front central part, above the lock zone), and the displacements of the load application points are measured. The maximum and residual displacements have to be lower than target values. Substantially with this test the formation of a visible impression on the bonnet surface has to be investigated. The points of application of load are defined with a geometric procedure. Also this analysis has been performed using the Abaqus software. Once again this test has not shown particular problems because all the displacements are well below than the limit target values.
At this point, in order to get a deep exam of the pedestrian safety performance, the three bonnets under evaluation, the new hybrid one and the two reference ones, have been tested on four additional impact points. These points have been chosen choosing the potential most critical points examining the structure of the bonnets and the engine compartment. A complete picture of the results of this last simulation loop, once again in terms of HIC_{15}, is shown in Table 6.

Table 6
HIC_{15} results for the additional impact points

HIC_{15}	Impact Point			
Solution	*C5*	*C6*	*C7*	*C8*
Reference	995	1061	1124	1050
Aluminium	865	1059	979	815
Hybrid	948	1308	1182	792

The results obtained at these additional impact points, substantially have confirmed the trend obtained at the first three considered points. It is possible to conclude that the best solution is the aluminium one because the decrease on the HIC_{15} values is the highest, once again there is a confirmation that the use of aluminium is the best choice for the bonnet design considering the technical performance. However also the proposed hybrid solution is very interesting, the results obtained for the pedestrian impact test are interesting and also considering the other performance the hybrid bonnet can be considered in target.
Before to conclude the development of the hybrid solution, also some economical considerations has been done. In particular, in this economical analysis the total, the industrial and the variable costs have been calculated. This evaluation has been done by means of cost models developed by Fiat Research Centre. The main results of this activity has put in evidence as the hybrid solution has a cost nearly comparable with the aluminium reference solution, it is also important to say that the analysis has been heavily influenced by the cost of raw materials.
It has been also interesting to examine the trend of these costs as a function of the annual production, but also in this perspective the curves of the hybrid solution and the aluminium one have substantially the same trend although there are some steps due to the substitution of the mould. For this reason for very low production volumes, the hybrid solution results to be cheaper, the opposite effects it has been obtained for very high production volumes.

PERIPHERICAL FRAME BONNET

Before to start with the design of the hybrid solution, some considerations on a peripherical frame bonnet solution has been done, in fact, as it has been put in evidence in the preliminary benchmarking activity, this type of solution can be considered a state of art. For this reason a simple modification has been made on the FEM model of the reference bonnet by erasing the central part of the inner structure, without changes in material and thickness. This type of bonnet has been tested for the pedestrian head impact, at the three initial considered impact points (C2C, C3D, C4C).
This solution has shown excellent results in fact, there is an important reduction of the HIC_{15} values. Due to the obtained interesting results in the first mentioned analysis, it was decided to examine in more details only the pedestrian safety performance of this bonnet, in particular all the impact points used up to now for the hybrid bonnet have been considered. The design used in this phase has been the same used for the preliminary analysis, it is shown in Figure 10.

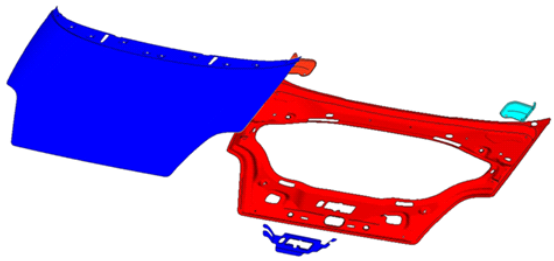

Figure 10. The examined perimeter bonnet.

On this geometry two different bonnets have been prepared, the first one has been made by the same material used for the reference solution, the second one has been an aluminium version, in particular, once again, for the external skin and the reinforcements a 6xxx series alloys has been used, instead for the perimeter inner structure a 5xxx series has been adopted. This choice of materials has been done starting from the information obtained in the preliminary benchmarking activity. When compared to the reference solution made by steel, the weight reduction reached by the perimeter bonnet made by steel has been of about 14%, instead for the perimeter bonnet made in aluminium the weight reduction has been of 46%. A global overview on the obtained results is shown in Table 7.
These results are quite interesting, first of all there has been a global reduction of the HIC values, but it is interesting to note as the use of aluminium, that is very important to obtain the weight reduction, has not led to significant improvements for the pedestrian safety, in fact at some impact points the best performance have been obtained with the steel version. This is substantially due to the higher

deformations obtained with the aluminium bonnet. There is a further confirmation that, in order to obtain the best pedestrian safety performance, it is necessary to start the design with a global approach considering all the design aspects and case by case, because also the near body structure is very important for the global behaviour. It is not possible to define at the beginning an optimum solution.

Table 7
HIC_{15} results for the perimeter bonnet compared to the previous solutions

HIC_{15}	Solution				
Impact Point	*Ref.*	*Al.*	*Hyb.*	*Perimeter bonnet in steel*	*Perimeter bonnet in aluminium*
C2C	1912	1876	2048	1637	1429
C3D	1382	1723	1739	918	833
C4C	941	837	852	380	526
C5	995	865	948	575	667
C6	1061	1059	1308	936	1100
C7	1124	979	1182	669	662
C8	1050	815	792	448	475

WIRE CONCEPT BONNET

From the results illustrated up to now, two fundamental aspects can be put in evidence. First of all it is clear that the multi material approach represents one of the best way to obtain excellent results in terms of lightweight and pedestrian safety without loss in others performance. A second important subject is that, to improve the pedestrian safety performance, a inner structure made with a distribute or perimeter design have to be preferred because they absorb better the crash impact energy against the pedestrian head. Starting from these considerations, a further concept of hybrid bonnet has been developed. The main idea for this further hybrid bonnet has been a thermoplastic inner structure made with a perimeter design and with a wire net central part. To better understand this solution it is possible to see Figure 11.
In particular, as it has already been done with the other previous solutions, it was decided to use an external metal panel, to reach the quality requirements, besides the inner structure has been though in thermoplastic to lightweight the structure. Once again, the material used for the external skin has been the series 6xxx aluminium and for the inner structure the same polyamide used in the previous part of the wok has been chosen. A first model has been designed. For what concerns the innovative inner structure, the perimeter has been taken by the reference structure, so it has the same shape and geometry, instead for the central wire part, the width of the sticks has been chosen 25 mm and the step between the stick about 100 mm. The thickness of the inner structure has been again 2.5 mm. The hybrid bonnet has been completed with the same reinforcements used in the reference subframe. The joint between the different parts has been thought by structural adhesive bonding. The weight reduction obtained with this first solution has been about 47% which is an excellent value if compared with those obtained in the previous part of this work. This first solution has been submitted to pedestrian impact tests on the same impact points used in the previous part of the work.

Figure 11. The wire hybrid concept bonnet.

The obtained results (summarised in Table 8) have been excellent because there has been an important reduction in the HIC_{15} value. At this point also the torsional stiffness has been considered, in order to evaluate if the bonnet can be suitable also from the point of view of the static performance. The results for this performance have not been very good in fact the obtained values are too low and very far from the minimum target. At this point a series of modifications have been though to improve the stiffness of this solution. In particular the influences of the elastic modulus of the adopted plastic material and the thickness of the inner structure have been taken into consideration. However, both these types of modification have not lead to a sufficient increase of the stiffness value, for this reason, the inner structure has been

partially redesigned defining a larger perimeter crown. Once again, the torsional stiffness results obtained after a simulation loop have been too low. To reach the stiffness target, at this point a further modification in the philosophy of the solution has been done. In particular it was decided to make the perimeter crown in aluminium always with a central wire part in thermoplastic. This last change has not influenced the weight reduction that remains about 44%. With these last modifications, the stiffness results obtained from the simulations result to be in target and even better than with the hybrid solution developed in the previous part of the activity. At this point a further simulation loop concerning the pedestrian head impact has been done, in order to evaluate if these last modifications have influenced also this performance. A summary of the obtained results are proposed on Table 8.

Table 8
HIC_{15} results for the wire bonnet compared to the previous solutions

HIC_{15}	Solution				
Impact Point	*Reference*	*Wire first version*	*Wire*	*Aluminum*	*Hybrid*
C2C	1912	1722	1766	1876	2048
C3D	1382	884	960	1723	1739
C4C	941	506	565	837	852
C5	995	781	656	865	948

Before to conclude the development of this hybrid solution, also some considerations on the manufacturing technology have been done. In particular the aluminium parts of this last proposed solution, can be made by common stamping technology instead the wire thermoplastic part can be made by different technologies such as injection or compression moulding but also some other possibilities can be taken into consideration. For what concerns the connection between the wire central part and the aluminium crown, some different joining technologies can be used, such as the riveting or the adhesive bonding.
The development of this second solution has been stopped at this point, without any economical consideration, in fact the main target of this second part of the work was to investigate the behaviour of this wire concept bonnet. Obtained results have confirmed the first idea. This solution has improved the performance in particular for the pedestrian safety because the central wire part distributes better the energy of an head impact and can avoid the contact between the deformed inner part of the bonnet and stiff part inside the engine compartment.

CONCLUSIONS

This work has illustrated a global overview on the different solutions which can be adopted for the bonnet of medium/low segment car, in order to reach lightweight and pedestrian safety targets.
First of all the development of an hybrid bonnet has been presented. Starting from a benchmarking activity an hybrid concept composed by a thermoplastic inner structure and an outside metal skin has been proposed. During the activity different types of materials for the different parts and some geometries for the inner structure have been evaluated. The final solution has been characterized by an aluminium skin and a short fibre reinforced polyamide inner structure with a specific design. This solution allows a weight reduction of about 30% compared to the reference solution with a further important reduction of the pedestrian head impact evaluated in terms of HIC_{15}. Also the manufacturing and the economical aspects have been taken into consideration during the development.
After that some considerations on the perimeter bonnet solutions have been done, they can be considered an excellent solution for the bonnet to reach the targets of lightweight and reduction of the risks of pedestrian and VRU head injuries.
At the end the study on a concept hybrid solution, characterized by an inner structure with a wire design has been illustrated. This last solution can ensure a better distribution of the impact energy between the bonnet and the pedestrian head, with a consequent reduction of the injury risks.

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