PEDESTRIAN SAFETY VALIDATION OF A HIGH PERFORMANCE THERMOPLASTIC COMPOSITE HOOD

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Abstract

GE Plastics pioneered the use of thermoplastics for vertical body panel applications (such as fenders, door skins and lift-gate skins), and now a thermoplastic composite material for horizontal automotive body panel applications (such as hoods, roofs and trunk lids) is under development. One of the challenges to be met by a new material for hood applications is to meet the new requirements for pedestrian protection that have been introduced in Europe and Japan. As one of the key technology developments carried out for the Hyundai HED-4 QarmaQ advanced technology demonstration vehicle developed by Hyundai and GE Plastics, a new hood design was created for manufacture with the HPPC sandwich. Semi-production compression-molding tooling was built, and parts were produced to enable a series of head-impact tests to be completed. The test results indicated that the energy absorption characteristics of HPPC allow such a hood to meet the pedestrian safety requirements without the need for extra intrusion into the engine bay.

Background

As OEMs continue to develop solutions to today's pressing environmental challenges, they are continually investigating methods and materials which will enable the production of lighter vehicles which are more fuel efficient and produce lower quantities of CO_2 per km driven. Several different material technologies and processes have been adopted for exterior body panel applications in order to achieve this goal, including:

- Pressed high strength steels, which may be used at thinner gauges than regular steels,
- Pressed aluminum,
- Injection molded thermoplastics,
- Injection molded thermosets,
- Compression molded fibre-reinforced composites, and
- Resin infused fibre-reinforced composites

GE Plastics pioneered the development of injection-molded thermoplastics for online-painted exterior body panels in vertical locations with the Noryl GTX* PPO/PA conductive resin family, and have more recently been focused on the development of a composite thermoplastic material that will be suitable for horizontal locations (such as the hood, roof and trunk lid). The development of HPPC (High Performance thermoPlastic Composite) technology is being carried out jointly by GE Plastics and AZDEL Inc. (a joint venture between GE Plastics and PPG Industries) with the aim of meeting the goals described in Table I.

Table I: Development targets for HPPC technology

Requirement	Target	Comment
Part stiffness	Similar to aluminum	
Part weight	Similar to aluminum	
Material CTE	Similar to aluminum	2.0×10^{-5} mm/mm/°C
Part total cost	Comparable to current solutions	Current light-weight solutions include aluminium, composite lay-up or SMC
Tooling cost	Lower investment than pressed aluminum or SMC	
Surface finish	Painted to Class-A appearance	Using either on-line or off-line paint systems
Energy absorption	Suitable for pedestrian safety body panel applications	Relevant for hoods in Europe and Japan

HPPC is a multi-layer composite material, comprised of a low-density core sandwiched between high-strength skins. AZDEL's SuperLite® chopped-fibre reinforced low-density thermoplastic sheet is used as the core. Figure 1a shows the layered construction of the product, and Figure 1b shows a cross-section through the layers.

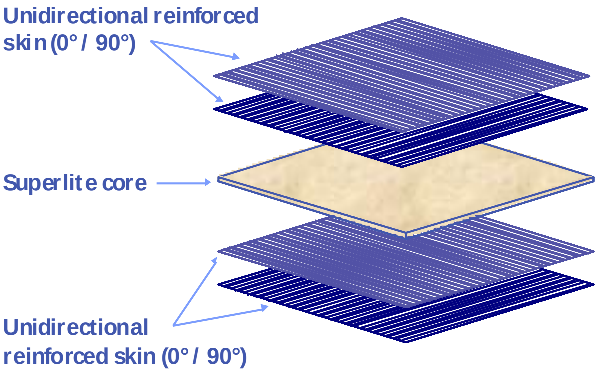


Figure 1a. The multi-layered structure of HPPC showing the 2 skin plies on each side of the Superlite® core

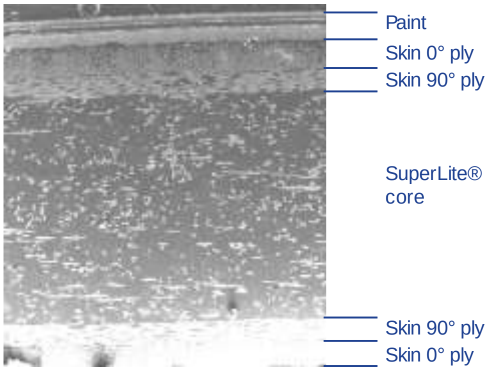


Figure 1b. Cross-section through HPPC structure showing the 0° and 90° oriented layers of continuous glass fibres on each surface of the low-density SuperLite® core

A paper was presented at the 2006 SPE Automotive Composites Conference describing early developments in this sandwich thermoplastic composite technology, along with observations from early work exploring the use of the CAGE® induction heating system from RocTool to minimise cycle time for the thermal forming process. The 2006 paper proposed further work to be carried out including confirmation of Class-A painted surface quality, optimisation of the induction heating process for cycle time improvement and the validation of head impact performance for pedestrian protection, the subject of this paper.

The challenge of developing a thermoplastic solution for horizontal body panels has focused the attention of material suppliers for many years. An early attempt by GE Plastics was the demonstrated on the Vector II concept car of 1987, using a compression molded glass-mat thermoplastic inner frame bonded to an injection molded thermoplastic outer skin (Figure 2). This solution met the mechanical and crash requirements for a hood, but needed improvement on dimensional tolerances and offered little weight saving compared with a steel hood.

Figure 2a. The Vector II concept vehicle developed by GE Plastics in Europe during the late 1980's featured an all-thermoplastic hood.

Figure 2b. The compression-molded chopped-fibre reinforced thermoplastic frame of the hood for the Vector II concept car (shown following a front barrier collision test)

Hence GE Plastics and AZDEL have focused their development efforts around the concept of a sandwich material that can offer the benefit of high stiffness plus weight reduction.

Pedestrian Safety Validation of an HPPC Hood

In order to validate the pedestrian protection performance of HPPC technology in full-size vehicle hood, it was decided to produce and test prototype hoods for the Hyundai HED-4 QarmaQ advanced technology demonstration vehicle using this new material. The development of the QarmaQ (Figure 3) is a joint project by Hyundai Motor Corporation and GE Plastics to demonstrate a range of new technologies that are being validated and implemented by Hyundai. The project has 3 key goals:

- To demonstrate environmentally friendly technologies that can lead to lower weight, reduced fuel consumption and lower CO2 emissions for a Crossover Utility Vehicle (CUV),
- To demonstrate a pedestrian friendly CUV design with the “Elastic Front” passive pedestrian protection concept, and
- To enable design and styling freedom through the use of innovative plastic materials

The use of HPPC technology for the hood outer skin and hood inner frame is a key element of the “Elastic Front” passive energy absorption concept in which a combination of energy absorbing geometries plus highly ductile materials can offer a light-weight solution for the demanding requirements of pedestrian protection testing. The front end of the QarmaQ is engineered to meet several different pedestrian safety requirements, including EEVC WG17 Phase 2, Euro-NCAP and Japan-NCAP.

Figure 3: The Hyundai HED-4 QarmaQ advanced technology demonstration vehicle features a prototype hood made using HPPC technology.

Pedestrian Protection Legislation

In order to reduce the number of pedestrian injuries and fatalities in highly urbanised Europe and Japan, legislators have introduced vehicle-testing rules intended to reduce the risk of serious injuries if a pedestrian comes into contact with the front-end of a moving vehicle. Legislators in China and Korea are considering similar pedestrian protection regulations, and vehicle manufacturers in Europe, Japan, Korea, Canada and the United States are involved in discussions on a “harmonized” Global Technical Regulation for pedestrian protection.

The European regulations are based on work carried out by Working Group 17 (WG17) of the European Experimental Vehicle Committee (EEVC), which developed a set of standards intended to reduce the risk of serious injury to pedestrians involved in impacts of up to 40 km/h. In 1991 EEVC proposed a set of component tests representing the three most important mechanisms of injury: head, upper legs and lower legs. These tests were incorporated into the consumer tests conducted by Euro-NCAP with the first results published in 1997. Early in 1999 the European Commission (EU) announced that it planned to introduce regulations to make the EEVC (now the European Enhanced Vehicle-safety Committee) requirements mandatory.

The first phase of the European regulations (Directive 2003/102/EC) came into force in July 2005, with the target of reducing the risk of serious injury to 50%. A second phase is proposed for introduction in 2010, with a reduced serious injury risk of 20%. In Japan the initial set of regulations (IHRA/MLIT) became effective in September 2005, with subsequent additional categories of vehicles required to meet the regulations by 2007, 2010 and 2012. The head impact test requirements for both the European and Japanese regulations are similar, with 2 tests covering child head and adult head impacts. The European test requirements include 2 additional tests covering lower leg and upper leg impacts. At present the upper leg impact results are for monitoring only, and are not critical for vehicle homologation, however they are included in consumer-oriented Euro-NCAP ratings. The tests are summarised in Figure 4. For the developmental HPPC hood described, only head impacts need to be considered.

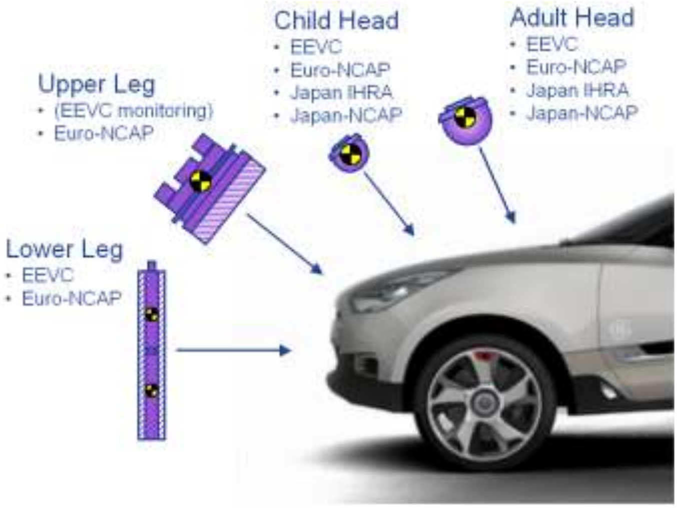


Figure 4. Graphical summary of the impact tests required under pedestrian protection legislation and consumer testing in Japan and Europe.

In order to determine if a particular design performs with an acceptable level of injury risk, acceleration measurements are taken from tests and then a numerical Head Performance Criteria (HPC) is calculated. Allowable limits for HPC (which have been correlated to levels of injury risk) and methods for assessing each design are specified in the regulations. HPC is calculated according to the following equation:

$$HPC = \left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a\, dt\right]^{2.5} (t_2 - t_1)$$

Where a is the resultant acceleration (as a multiple of g) and t1 and t2 are the two time instants (in seconds) defining the start and and of the recording for which HPC is a maximum. Values of HPC for which the time interval t1-t2 is greater than 15 ms are ignored for purposes of calculating the maximum value.

The allowable limits for HPC under the European and Japanese regulations are listed in Table II.

Table II: Head Performance Criteria allowable limits

Region	Requirement	HPC Limit
Europe	Legal requirements	2/3 of area with HPC ≤ 1000 1/3 of area with HPC ≤ 2000
	Euro-NCAP consumer tests	HPC ≤ 1000 - 1350
Japan	Legal requirements	Hood divided into sub-areas I, II and III. Sliding scale for HPC from 650 to 2000
	Japan-NCAP consumer tests	Hood divided into sub-areas I, II and III. Sliding scale for HPC from 650 to 2000

Hood Design for Pedestrian Protection

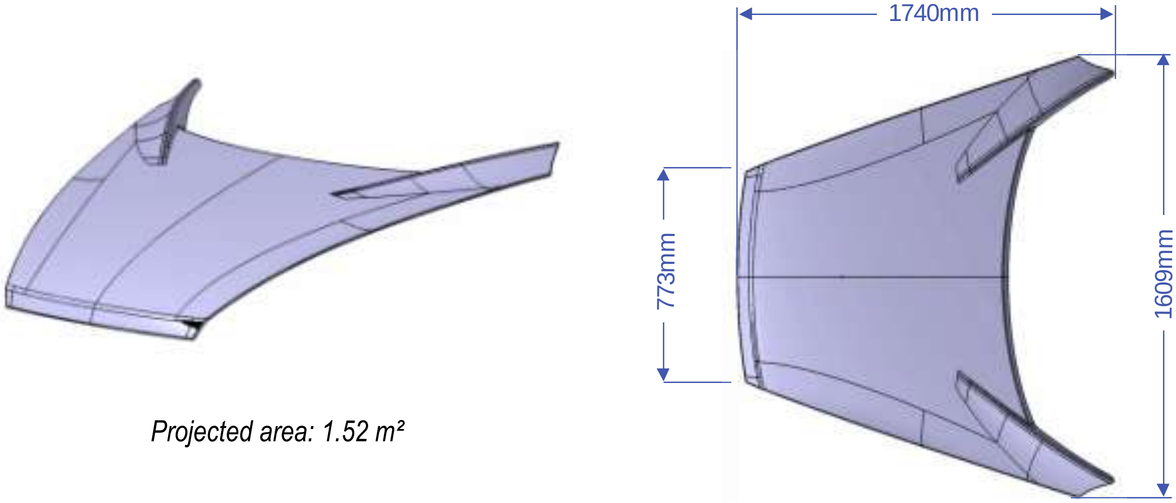
Since HPPC is a new type of sandwich composite material, the first step in creating a design for pedestrian protection was to generate an initial set of material data. The properties of the AZDEL SuperLite® core have previously been characterised and this allowed the semi-empirical estimation of properties for the skin layers to be developed based on testing of the complete sandwich. Tensile and bending tests were carried out (under static conditions) to generate the preliminary properties shown in Table III. However we recognise that for design purposes OEM engineers require a higher level of detail, so further work is continuing to characterise the property profile for each of the individual layers in the HPPC sandwich over a range of temperatures and strain-rates.

Since HPPC is a new type of sandwich composite material, the first step in creating a design for pedestrian protection was to generate an initial set of material data. The properties of the AZDEL SuperLite® core have previously been characterised and this allowed the semi-empirical estimation of properties for the skin layers to be developed based on testing of the complete sandwich. Tensile and bending tests were carried out

Table III: Preliminary HPPC properties used for hood design

Layer	HPPC Test Sample Construction	Property	Value
Core	Core thickness: 1.70mm Core density: 1600 g/m²	Tensile modulus, E_{11} (parallel to fibres)	10.6 GPa
		Tensile modulus, E_{22} (90° to fibres)	3.5 GPa
		Shear modulus, G_{12} (in plane)	4.0 GPa
		Shear modulus, G_{13} & G_{23} (out of plane)	1.0 GPa
Skin (2 plies)	Skin thickness: 0.30mm Skin density: 800 g/m²	Tensile modulus, E_{11} (parallel to fibres)	30.0 GPa
		Tensile modulus, E_{22} (90° to fibres)	2.0 GPa
		Shear modulus, G_{12} (in plane)	4.2 GPa
		Shear modulus, G_{13} & G_{23} (out of plane)	1.0 GPa

In order to design the QarmaQ hood to meet the European and Japanese pedestrian safety regulations, the design goal was to keep the predicted HPC values below 1000 for 2/3 of the surface area of the hood, and below 2000 for the remaining 1/3 of the hood surface. Following the design freeze on the clay models and completion of the surfacing and panel split-up by Hyundai Europe Design the general layout and dimensions of the hood outer skin are shown in Figure 5.



Projected area: 1.52 m²

Figure 5: General layout and dimensions of the QarmaQ hood outer skin

To meet the pedestrian protection requirements, a trade-off must be found between stiffness and deflection. The hood must be “soft” enough to deflect and absorb the energy of the impact without subjecting the head-form to excessive acceleration, but it should be stiff enough to minimise deflection or intrusion into the engine bay. Excessive intrusion would require an increase in the packaging space between the inner surface of the hood and hard-points in the engine bay such as the shock absorber mounts or engine components, and this is not desirable since it requires a more voluminous front end. Typical passive solutions already adopted by OEMs include using thinner gauge steel in combination with increased deformation space and using aluminium in combination with increased deformation space. Active solutions include pop-up systems to raise the hood and increase the deformation space. Hood-covering air bags have also been proposed. A hood manufactured from HPPC offers the potential to have the same or better performance as thin-gauge steel or aluminium and to avoid the added cost and weight required for active pop-up or airbag systems. It should be noted that the hood works as part of a system that also includes the hinges and bump-stops as they will also absorb energy. These elements were included in the testing, and the hinges were modelled in the initial CAE design work.

As well as meeting these pedestrian protection requirements, the hood design should also meet all functional requirements such as bending stiffness, torsional stiffness, centre point loading stiffness, hood slam durability, dent resistance, flutter under aerodynamic loads, hinge stiffness and offset barrier crash, as well as low-speed insurance classification tests. These load cases and test requirements are not covered in this paper.

Based on the final surface for the hood and the overall vehicle design, a number of impact locations were selected for modeling and subsequent testing. The procedure for selecting these impact locations is defined in the WG17 test requirements and includes calculation of Wrap-Around Distance (WAD) from the ground up to the surface of the hood. A total of seven locations were selected as points of interest, as described in Table IV however a larger number of impact locations would be explored for actual vehicle homologation tests.

Table IV. Description of impact locations and test types

Location	X, Y, Z Coordinates	Impact type
1	716, -250, -104	J-NCAP Child E-NCAP Child (“soft” central area, offset)
2	476, 0, -22	J-NCAP Child E-NCAP Child (“soft” central area, centreline)
3	81, 0, 65	J-NCAP Adult E-NCAP Adult (“stiff” area over water separation box)
4	17, -450, 66	J-NCAP Adult E-NCAP Adult (“stiff” geometry area, offset)
5	295, -456, -6	J-NCAP Child E-NCAP Adult (“stiff” geometry area, offset)
6	980, 0, -200	J-NCAP Child E-NCAP Child (“stiff” latch area, centreline)
7	970, -190, -205	J-NCAP Child E-NCAP Child (“soft” front area, centreline)

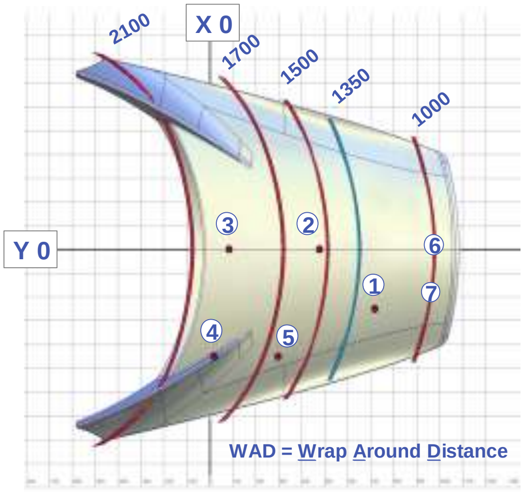


Figure 6a. Plan view of impact locations showing coordinates and Wrap-Around Distance lines.

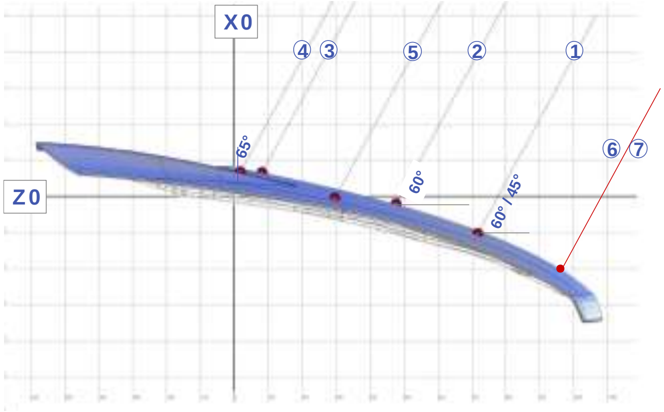


Figure 6b. Side view of impact locations showing impact angles.

ABAQUS software was used to carry out dynamic simulations of the various impacts which were considered, and HPC values were calculated from these simulations. Several iterations were carried out on a number of different design concepts in order to explore the effect of different energy-absorbing shapes for the inner frame on the calculated HPC. An example of these analyses is shown in Figure 7. As the material properties were only preliminary and not determined from dynamic testing, the calculated HPC values and deflections were not expected to be accurate in the absolute sense, however they were useful for determining which design alternatives offered better or poorer performance. The most promising design (Figure 8) was selected for prototyping and testing.

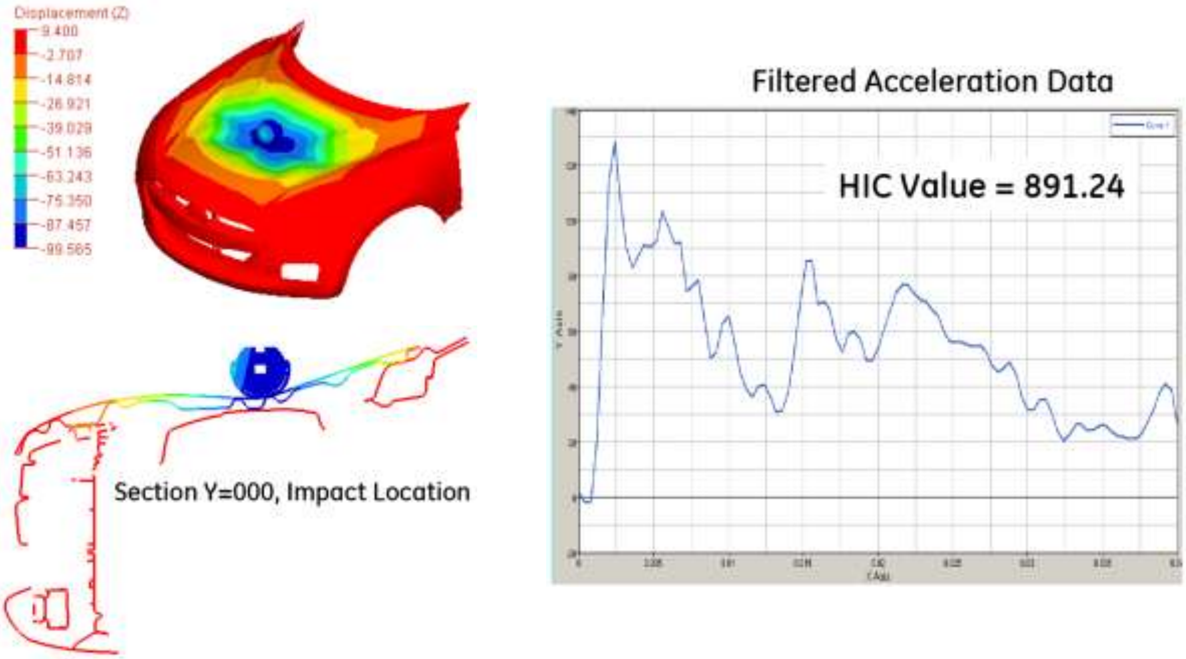
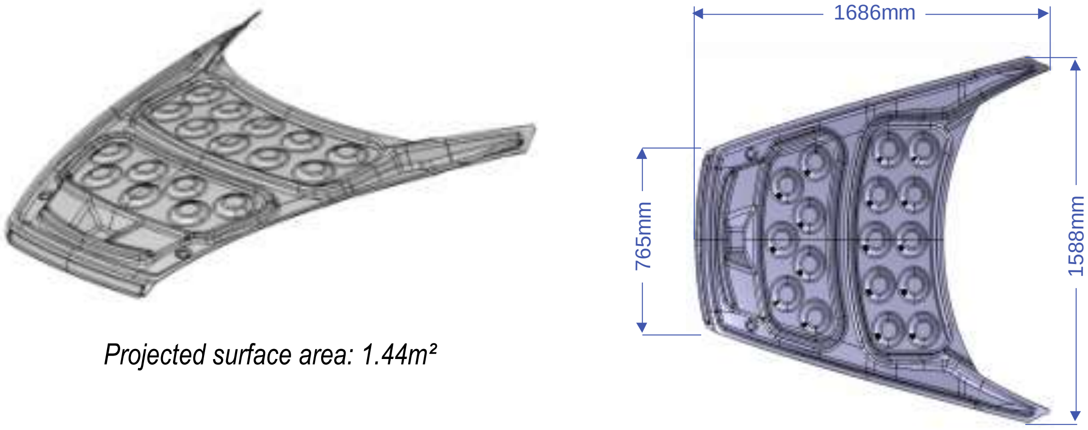


Figure 7: An example of deflection and HPC calculation from dynamic CAE simulations of a proposed inner frame design.



Projected surface area: 1.44m^2

Figure 8: General layout and dimensions of the selected design for the QarmaQ hood inner frame, based on predicted HPC performance from CAE simulations

Prototype Hood Fabrication

The first step in fabricating the prototype hoods was to hand-fabricate sheets of online-paintable HPPC material by spot-welding two plies of continuous glass-fibre reinforced PC/PBT tapes to both sides of a PBT SuperLite® sheet (Figure 9). The tapes were over-lapped at the edges to ensure complete coverage of the continuous glass fibre reinforcement in the skin layers. Two plies were spot-welded in place, at 0° and 90° orientation to the machine direction of the SuperLite® sheet.

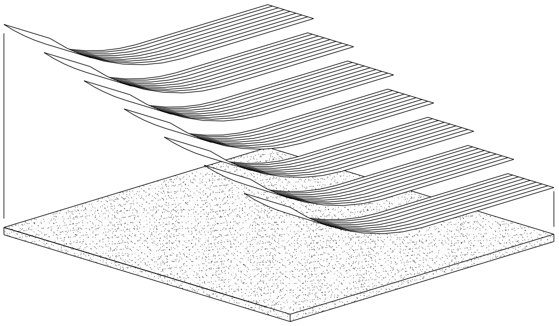


Figure 9a. The first step in hand-lamination of HPPC sheets, spot welding of 90° continuous fibre reinforced tapes onto SuperLite® core to form the first skin ply.

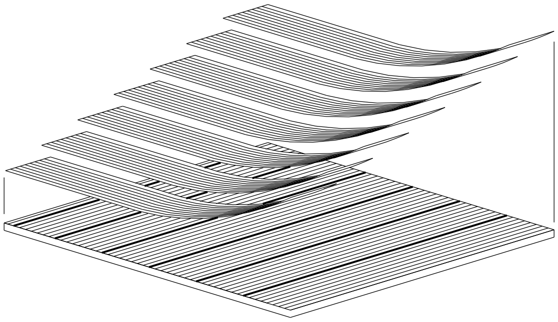


Figure 9b. The second step in hand-lamination of HPPC sheets, spot welding of 0° continuous fibre reinforced tapes over the top of the 90° ply.

This hand fabrication process approximates the proposed roller lamination process that is expected to be implemented in commercial production of HPPC sheets (Figure 10), however it does allow for pockets of air to be trapped between the 2 plies of the skin. This can lead to minor surface defects once the sheet is formed into a final part. These trapped air pockets can be eliminated by vacuum consolidation of the sheets however this is difficult to carry out on such large sheets and was not done.

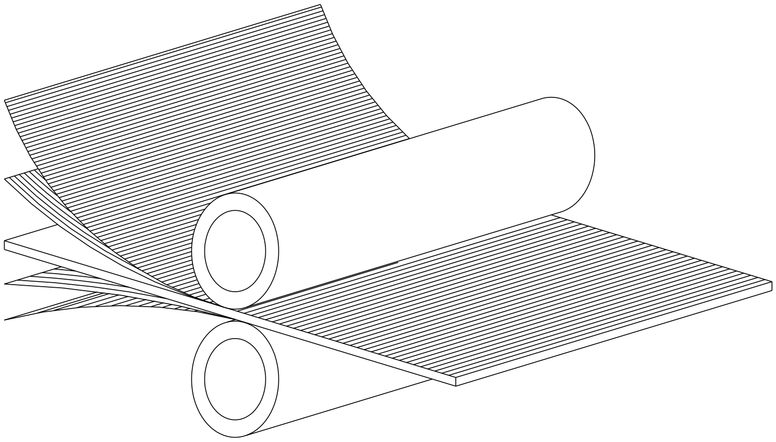


Figure 10. Schematic layout of proposed roller lamination process for mass production of HPPC sheets.

The CAD data from the proposed designs was transferred to RangerPlast in Italy who milled matched tools for the outer skin and the inner frame from aluminum (Figure 11). Since these were prototype tools an induction heating system was not incorporated in the tool construction since minimising the forming cycle time was not a major concern for these hand-fabricated prototypes.

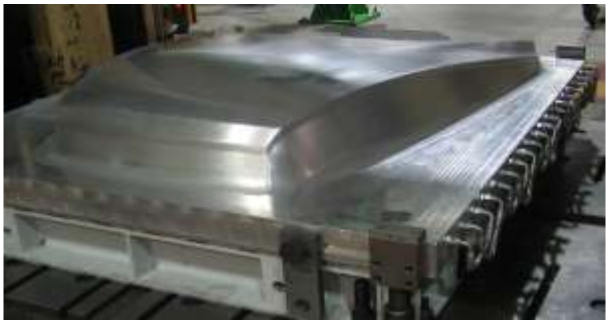


Figure 11a. Aluminum tool core for hood outer skin.

Figure 11b. Aluminum tool core for hood inner frame.

The hand-laminated HPPC sheets were prepared for heating and forming by clamping handles onto each corner to make it easier to manually transfer the heated sheet from the pre-heating oven into the press. The sheets were pre-heated at temperatures ranging from 265°C to 285°C for between 240s and 300s. The pre-heated sheet was then transferred manually to the press where the tool (pre-heated to 150°C) was closed and clamping pressure applied. Clamping pressures between 1000T and 3000T were tried in combination with holding times between 20s and 300s. Parts formed at lower clamping pressures exhibited surface defects due to air bubbles trapped between the laminations of skin plies (an artifact of the hand-lamination process which is not expected to be seen in mass-produced sheet laminated between rollers). A summary of the process steps undertaken to form the HPPC outer skins and inner frames is shown in Figure 12.

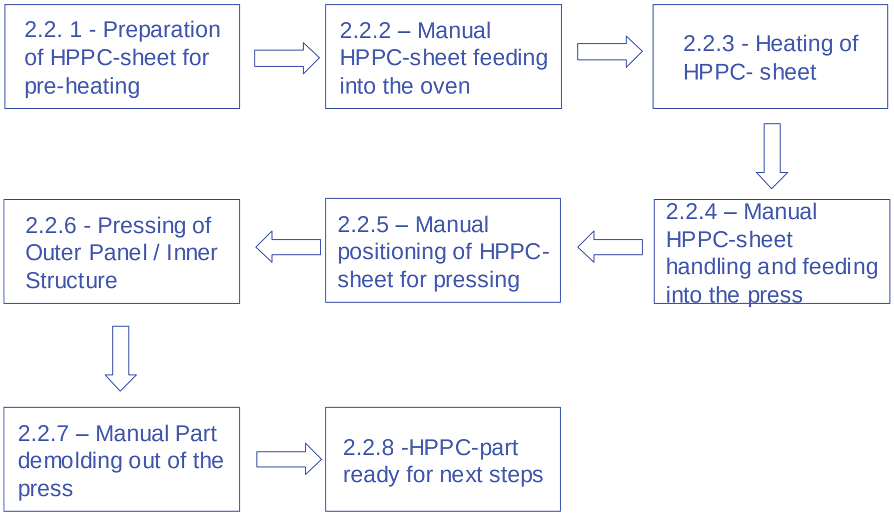


Figure 12. Summary of process steps for forming of HPPC hood prototypes with manual sheet handling

Once the parts were formed, the edges were manually pre-trimmed with a hand-held jigsaw to remove the bulk of the unwanted edge material, then clamped into a trimming frame (Figure 13) and fine trimmed with a CNC router. This process ensured repeatable dimensions as well as an acceptable edge finish.

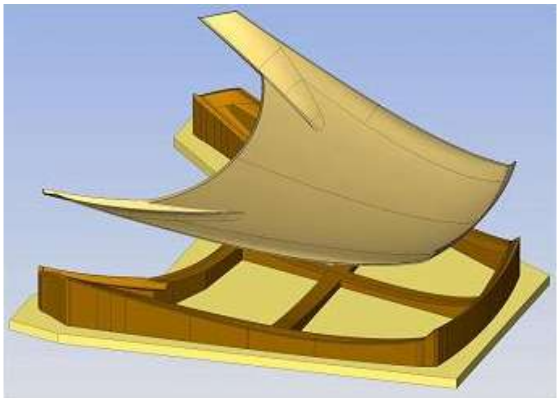


Figure 13a. CAD model showing HPPC outer skin and clamp-frame for edge trimming by a CNC router (image courtesy of RangerPlast).

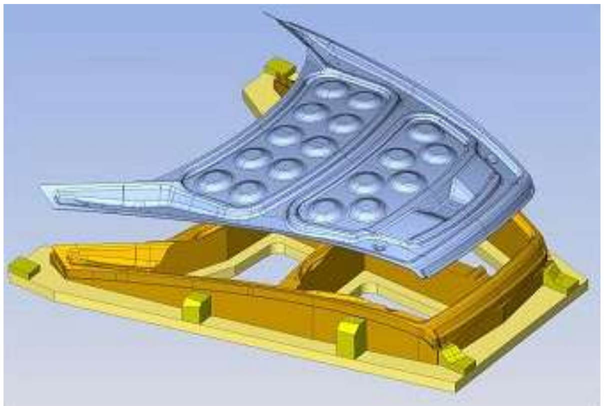


Figure 13b. CAD model showing HPPC inner frame and clamp-frame for edge trimming by a CNC router (image courtesy of RangerPlast).

Once the parts were trimmed to size metal inserts were bonded into place on the top surface of the inner frame to reinforce the attachment points for hinges, gas-struts and latch. In order to activate the PC/PBT surface, Dow Betaprime™ 5404 primer was applied to the areas to be bonded. The adhesive used to attach the metal inserts was Dow Betamate™ 2810/1S, allowing an open time of 6 minutes. Once the inserts were cured the outer skin was bonded to the inner frame (Figure 14) using the same primer with Dow Betamate™ 2810MV which has an open time of 8-10 minutes which allows more time to apply the adhesive, position the parts relative to each other and clamp the parts together for curing (Figure 15). The parts were clamped together using a clamping frame and the cavity half of the outer skin tool. For the curing phase, the tool was heated with water to a temperature of approximately 60°C and a curing time of around 20 minutes was allowed.

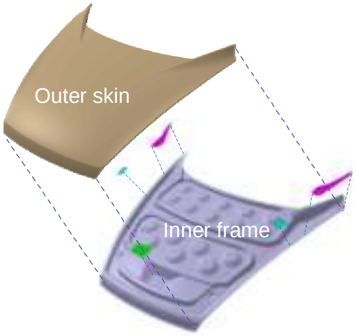


Figure 14a. Exploded view of the hood assembly showing HPPC outer skin and inner frame with metal inserts for hinges, gas-struts and latch.

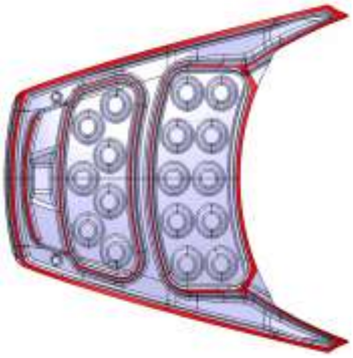


Figure 14b. Upper surface of HPPC inner frame showing bonding area (highlighted red).

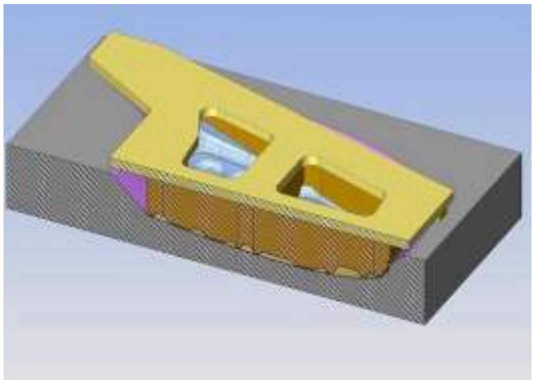


Figure 15a. Cutaway view showing the pressing frame used for clamping the hood assembly into the cavity half of the outer skin tool (image courtesy of RangerPlast).

Figure 15b. A hood assembly curing with the pressing frame holding the parts in place in the cavity half of the outer skin tool.

The completed hood assembly was then painted by hand in a spray-booth using a two-layer paint system. First any excess glue was removed by hand trimming, and then the edges were sanded by hand to remove sharp corners left from the CNC milling. Then a filler/primer coat was applied and allowed to dry. Then a matt black topcoat was applied, the matt finish ensuring that reflections were not apparent in the high-speed video images of the part testing. The painting process is summarised in Figure 16. This series of steps represents a hand-fabricated prototype process only, since the developmental goal of the HPPC project is to develop a material that can be painted online in the same automotive paint line along with the rest of the body in white.

Figure 16a. Primer coat being applied to the completed hood assemblies.

Figure 16b. Hood assemblies with primer coat applied.

Figure 16c. Completed hood assembly with matt black topcoat.

Pedestrian Protection Testing

Testing Set-up and Procedure

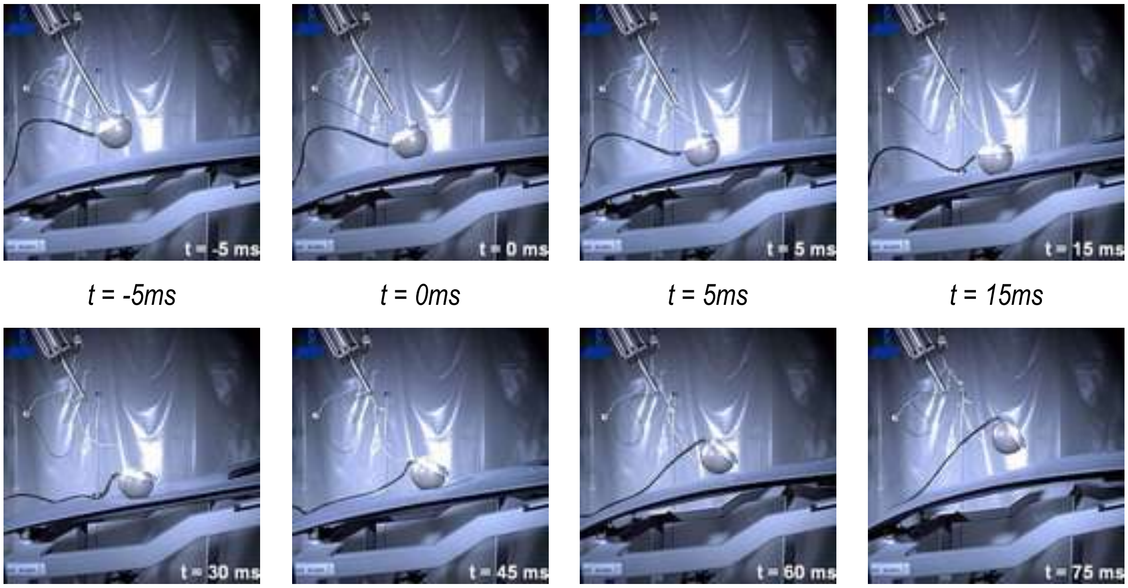
The completed hood assemblies (24 parts in total) were shipped to the pedestrian protection testing laboratory of IAV GmbH in Gifhorn, Germany. A support frame was designed and constructed to simulate the attachment points on the QarmaQ body. Standard hinges and latches from the Hyundai Tucson were used for testing purposes. A laser distance-measuring device was mounted under the centre of the hood to measure the maximum deflection directly underneath each impact location. The testing set-up is shown in Figure 17.

Figure 17a. Overall view of the impact testing set-up showing the hood assembly mounted on the support frame, impactor launcher and laser measurement device.

Figure 17b. Close-up detail of hinge attachment to support frame.

Figure 17c. Close-up detail showing the laser distance-measurement apparatus positioned under the hood to measure intrusion into the engine bay.

A series of 24 impact tests were carried out to measure the HPC value at each impact location according to the test conditions for the impact types listed in Table IV earlier. For each test the impact speed, impact angle and impact location were set according to the test method to be performed. The impact was then carried out, as shown in the sequence of images in Figure 18 for test location 2.



t = -5ms *t = 0ms* *t = 5ms* *t = 15ms*

t = 30ms *t = 45ms* *t = 60ms* *t = 75ms*

Figure 18. Sequence showing head-impact on location 2 (Euro-NCAP adult head, 40km/h, 60°)

The result of each test is a trace of measured accelerations vs. time (Figure 19) and the maximum deflection measured under the hood. HPC can then be calculated from the resultant acceleration.

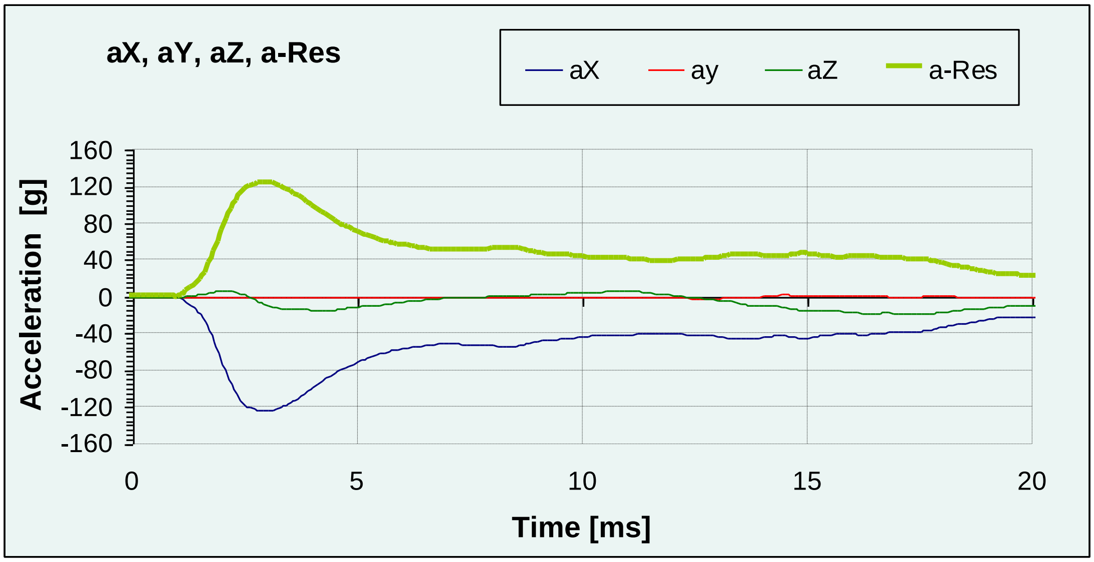


Figure 19. Measured acceleration data (in x, y and z directions) and calculated resultant acceleration for an impact on location 2 (Euro-NCAP adult head, 40km/h, 60°)

Head Impact Test Results and Observations

The measured HPC values for each impact location are shown in figures 20 and 21. If more than one test was carried out at each location the average of all tests is shown. The HPC values shown are also normalised to account for minor variations in the impact speed that is measured during each test. For example, if the target impact speed for a given test is 40km/h and the measured impact speed is 39.5km/h the measured HPC value is normalised to the speed of 40km/h.

The first observation made during the testing was that the HPPC hoods as designed for the QarmaQ can withstand these pedestrian safety tests with very little obvious damage. The amount of local strain that the material experiences appears to be within the elastic limit for this material.

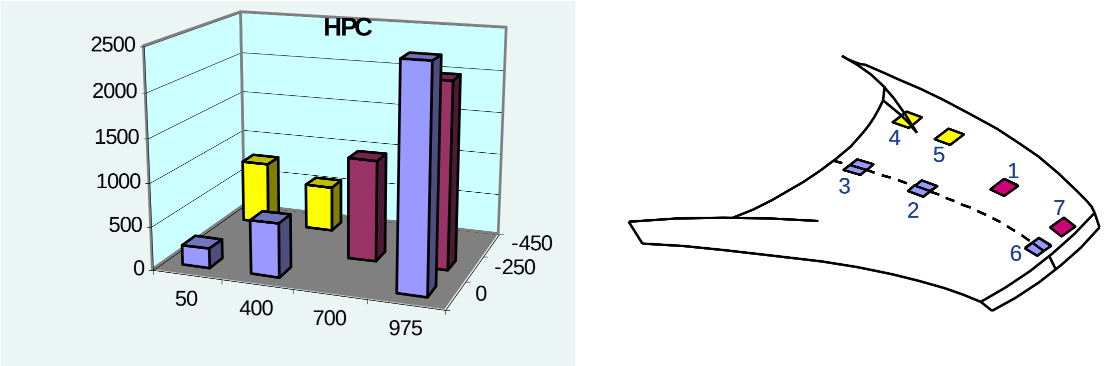


Figure 20. Measured HPC values for Euro-NCAP tests

The second observation was that the target of achieving HPC values below 1000 for 2/3 of the hood surface area was achievable. Most measured HPC values were between 300 (minimum 201) and 800 (maximum 810) for the "soft" areas of the hood (locations 1, 2 and 3), with deflections between 44mm and 100mm (Figures 18 and 19). As expected the HPC values for the "stiff" areas of the hood over the latch and near the bump-stop (locations 6 and 7) were quite high (2600 and 2100). In an actual vehicle design, we expect it would be possible to reduce these values by using deformable latch and bump-stop mounting points, since in the testing these were absolute hard points, attached directly to the support frame.

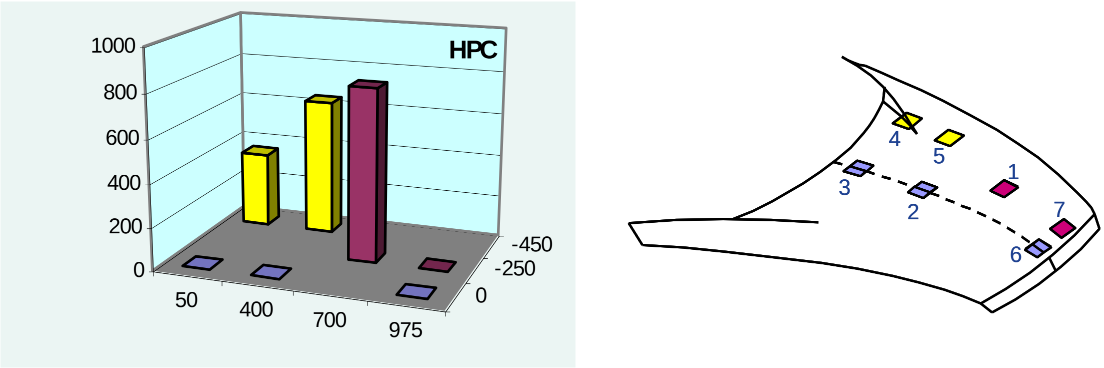


Figure 21. Measured HPC values for Japan-NCAP tests

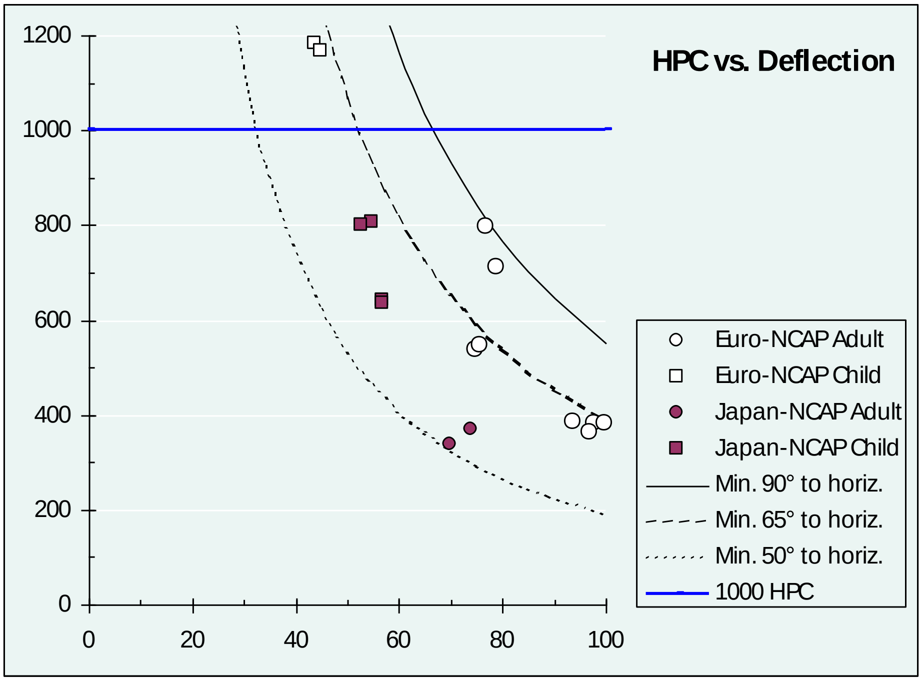


Figure 22. Measured HPC values plotted against maximum deflection. The theoretical minimum curves (after Zellmer and Glaeser, 1994) are also shown.

The Effect of Hard-Points

The effect of including a hard-point under the centre of the hood at location 2 was investigated by placing a steel beam across the width of the test frame at this point. Three tests were carried out, with differing distances between the beam and the inner surface of the hood (Figure 23). It was only when the hard-point was located 60mm below the surface of the hood that the HPC value went above the limit of 1000, indicating that a deformation distance of approximately 70mm might result in an acceptable HPC value.

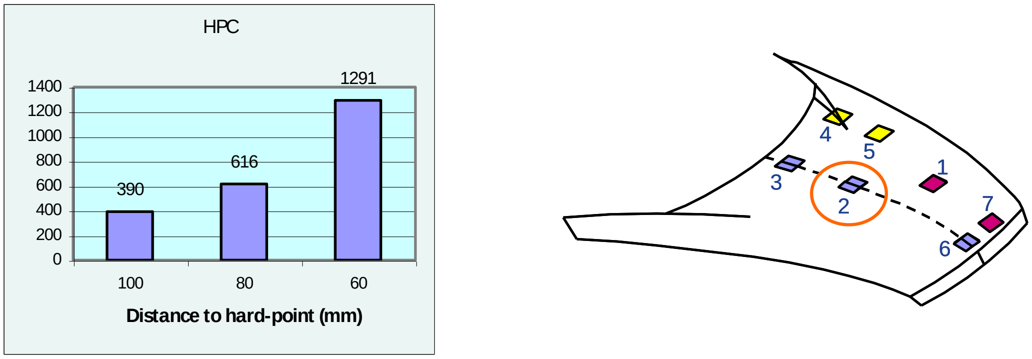


Figure 23. Measured HPC values for Euro-NCAP tests at location 2 with hard-point located below the hood surface at varying distances

The Effect of Repeated Impacts on the Same Location

Although it is not a requirement of the test methods, the effect of multiple impacts in the same location on the same hood was also investigated, with a repeat of the impact on location 2 for Euro-NCAP adult conditions carried out on two of the hoods. The results were surprisingly consistent, with HPC values of 388 and 394 for the first hood with a repeated impact and 393 and 386 for the second hood (Figure 24). This may indicate that the hood is in fact over-designed, remaining within the elastic limit for the material. The ability of the hood to survive multiple impacts on the same location was not a design goal.

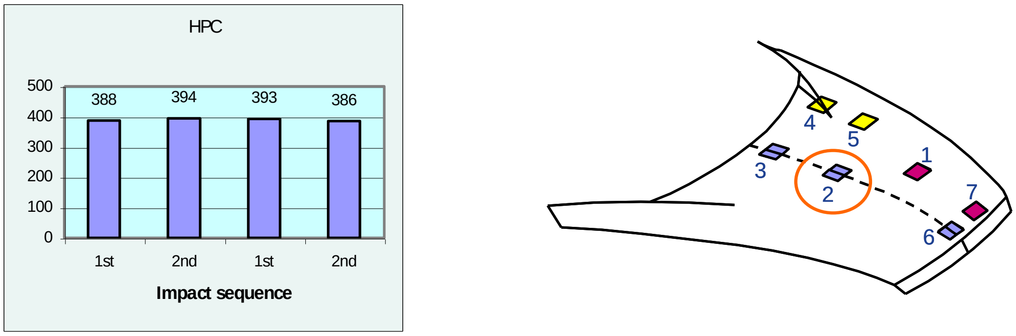


Figure 24. Measured HPC values for Euro-NCAP tests on 2 different hoods with repeat impacts at location 2

Conclusion

The prototyping and testing of the QarmaQ hood in HPPC material has successfully indicated that this new material offers the potential for production of composite automotive hoods that are required to meet the pedestrian safety regulations in Europe and Japan. As it stands, the hood design that was selected could be considered as over-designed, due to the absence of non-elastic deformation or local failure of the hood.

Future Work

Future development work will continue in several distinct areas. The construction of full-size prototype hoods for the Hyundai QarmaQ technology demonstrator vehicle will allow the completion of hood testing according to Hyundai homologation requirements (full mechanical, dimensional and crash testing). Development of the HPPC sandwich composite material will continue, completing development to achieve Class-A painted finish out of the tool as well as material characterisation based on each layer in the sandwich construction. And finally, HPPC process development will continue, investigating minimisation of cycle time and energy requirements, “net shape” molding (with the sheet pre-trimmed to the tool size, so edge trimming is less complex), and tool edge design to minimise edge-trimming requirements.

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