Developments in Thermoplastic Door Modules

Maria Ciliberti, *Owens Corning Automotive, Novi, Michigan, USA*
Warden Schijve *DSM Research, DADC Geleen, , the Netherlands*

ABSTRACT

The use of door modules as a pre-assembled functional unit inside a car door is discussed. This includes reasons why a door module should be used, and why a long glass fibre reinforced PP material is a good choice. As an example the development of the door modules for the new Ford Fiesta is given, including the mechanical and production design of the StaMax P carrier. Special attention is paid to the excellent dimensional reproducibility of this material. Further integration potential for future door modules is also highlighted.

KEYWORDS: **Door Module, Composite, Design, Dimensions**

1. INTRODUCTION

Recently many different types of semi-structural composite materials, mostly based on a thermoplastic Polypropylene matrix have appeared on the automotive market. Already well known are the GMT (Glass Mat Thermoplastic) materials, which are processed by compression moulding. GMT materials are now more and more being replaced with other types of semi-long fibre reinforced PP materials.
An example of such a new material is StaMax P [1], consisting usually of 12 mm long pellets containing glass fibres with the same length, covered with PP matrix, see figure 1.

Figure 1. StaMax P pellets

The material is usually processed by injection moulding. It may be used for semi-structural automotive applications, where it often replaces steel parts. Typical applications are:

- Integrated front-end modules
  (in short: IFEM or "front-end")
- Bumper beams,
  with or without integrated crush-cones
- Instrument panel carrier,
  possibly with "cross-beam" function
- Door modules,
  both for passenger and hatch-back door.
- Underbody shields,
  both under the engine and the car

In this article, as an example, the passenger door module will be discussed. The door module is a pre-assembled item that is fitted into the metal door structure, and contains numerous functional items, such as locks, window regulators, speakers, etc., see figure 2.

Figure 2, Example of door module fitted in metal door.

Recent examples of door modules are the ones for the new Ford Fiesta, see e.g. figure 3, showing the assembled forward door module.

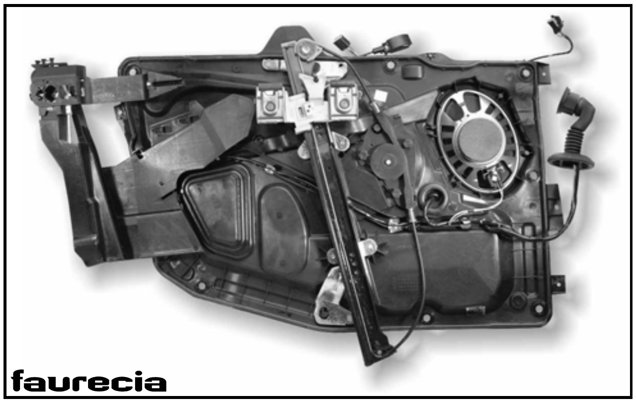

Figure 3, New Ford Fiesta forward door module, carrier material is StaMax P 30YM240.

2. Why use a door module?

Up until today, most cars don't have door modules. Historically seen there was no need for such a part, as functional items could also be mounted directly to the metal inner door structure. In the past there were not very many functional items: Mostly hand-driven window regulators (small pre-assemblies) could be fitted to the metal inner door structure. Loudspeakers to the door trim panel and other parts to the metal structure and/or trim panel. However in time the functional accessories of cars are increasing, meaning also more functions inside the door. For new models one can think of:

- Passenger control panel
  Regulating windows, and lock functions
- Lock, including motors,
- Door opening latches
- Anti-theft devices
- Side mirror adjustment
- Window regulator
  Motor, window guides
- Door handle fixations,
  Pull-cup support
- Arm rest support
- Storage functions
- Speaker
- Crash energy absorption elements
- Vapour seal
- "Door open" safety light
- Ambient lighting
- Cables to control all these items
- etc.

Note that side-airbags are not in the list above. Most car manufacturers feel that these can be better positioned on the chair, where it always has the correct position relative to the driver or passenger.
Of course one can mount all the listed items in the car assembly line. Numerous stations will be required, covering a lot of assembly line space. This is against the trend at many car manufacturers, who wish to shorten their assembly line to reduce cost. Supply of all these items in one ready module, preferably also "just in time", will reduce the assembly cost, and also logistic cost, as the stock can be greatly reduced.
More important however is the quality improvement that can be obtained by letting a supplier assemble all components on one semi-structural carrier. It is then far more easy to obtain the correct position of each item in space, and assembly itself is much easier to do. Also the responsibility for the correct functioning of the module can be taken over by the supplier.
Another quality improvement is obtained by using a so-called "closed" carrier system, as shown in figure 3. In this case the carrier completely takes over the function of the vapour seal, which in traditional cars is often a bonded plastic foil. This foil is very susceptible to damage after servicing or repair actions, often resulting in problems, such as corrosion and malfunctioning of the window regulator motor. The prevention of these in-service problems by a solid closed door module, can also yield significant cost savings.
Of course it is always difficult to quantify quality improvement and assembly improvement in terms of cost. Still a lot of car manufacturers don't use door modules, as they think that an extra part is added to the door that wasn't there before. Depending on the amount of items inside the door this may be true. However, as complexity and amount of functions increases and quality requirements become higher, there is no doubt that in the end door modules are more economical, and thus will be applied more and more in the future. In this respect a similar growth in usage is expected as is seen already in car front-end modules.

3. Material choice for module carrier

Traditionally structural or semi-structural items in cars are made of steel. Reason is the unmatched material stiffness and relative low material cost. It is therefore not surprising that earlier door modules have been made from steel, e.g. see the VW Passat module in figure 4. Reinforced plastic is

much lighter and offers more design freedom than sheet metal.
To start with, the density of e.g. 30% long glass reinforced PP is only 1.12, while that for steel is 7.85. That means a factor 7 difference! Unfortunately one cannot replace the steel part with exactly the same design in plastic. In that case the part would have a dramatic low stiffness, due to the much lower modulus of elasticity. However the shape of the plastic part can be very different due to the injection moulding production process. The sheet metal part will be more or less flat, with local depressions to increase the stiffness. In contrast the plastic part may be equipped with the most optimal shaped ribs at locations where they are needed. Somewhat deeper ribs, or hat-sections profiles, can compensate for the lower material stiffness.

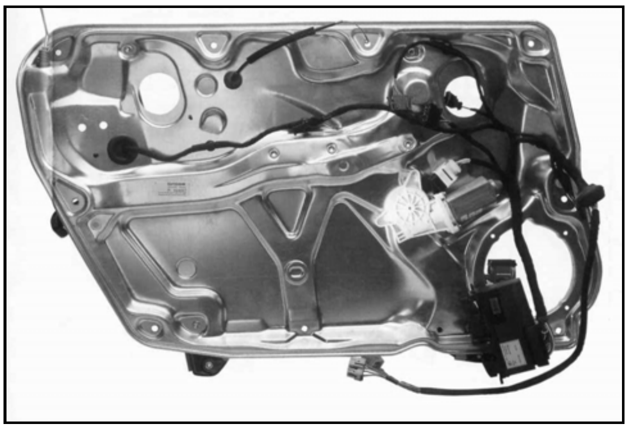

Figure 4, VW Passat sheet metal door module (Brose).

As a rough indication of possible weight saving, consider a steel part with some depressions, wall-thickness 0.8 mm. Consider a long glass PP part with wall-thickness of 2.0 mm and ribs included, a spread-out wall thickness of 3.0 mm. It is then easily estimated that the composite part will show a weight saving of 50%. Or for a small to mid-size 4-door car: in total 4 kg per car! In times that weights of new models are ever increasing, as is attention for lowering the fuel consumption, this is not unimportant.
Due to the different shapes of the metal and plastic part, stiffness and strength will not be the same for each different loading condition. What will come as a surprise to many people is that the strength of a composite part can be easily higher than for the metal part. This has to do with the relative low yield stress of steel, which can be formed into complex shapes as shown in figure 4. Even though the yield stress of the composite material is lower, the much more efficient structural shape can more than compensate for that, resulting in a high strength component.
Also, many people used to metal designs, are afraid of creep in plastics. In practise, for long glass reinforced PP materials, creep is never a problem, even for temperatures around 100°C. Reason for this is that high peak loadings are not present during hundreds of hours but only during short times. Long time high temperature exposure is combined with much lower load levels, and especially the long glass fibre network present in the moulded part, guarantees that no creep deformation will take place.

Perhaps even the best reason for using plastic instead of metal is the much greater design freedom. It opens possibilities to integrate many components, without having to use numerous special fixing brackets, and thus reduces cost. And of course, less separate parts means better control of dimensions, and thus a quality improvement.

Other reasons for using composite material are of course the much better corrosion resistance of the material, and the fact that no anticorrosion treatment is necessary.

One might think that the lower failure elongation of the composite material is a disadvantage over metal, as a tough material may be of advantage for side impact protection. However here again one should not just copy the metal design in plastic. E.g. Faurecia has applied a break away pad in it's door module, supported by foam for energy absorption. In this way a very controlled energy absorption takes place during side impact, that would simply not be possible in a metal structure.
Of course the composite door module will break during a side impact crash. This will not lead to sharp segments, injuring the passengers. One should also think of dashboard carriers, which are often made from long glass PP materials, and don't cause injuries at head or knee impacts. What also helps, is the failure behaviour of long fibre thermoplastics, which even at low temperatures don't show the brittle behaviour of short glass reinforced PP materials.
For controlled energy absorption, many other solutions also exist. Well known are the "honeycomb" structures, designed for buckling. And in the case of high stiffness and strength materials, one can design for controlled crippling and/or crushing, see figure 5.

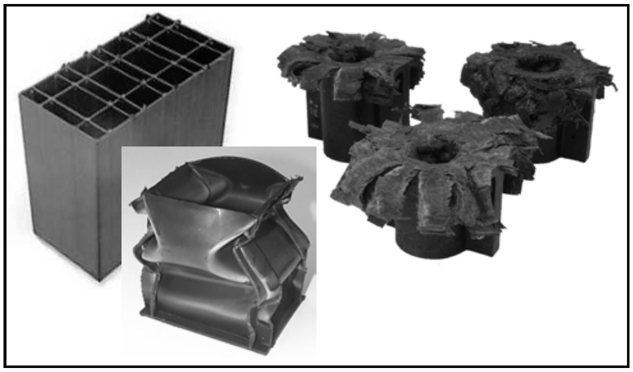

Figure 5, Energy absorption by buckling of a grid (left) and crushing of cylinders (right)

Such structures can be easily integrated in a composite door module, and also wouldn't be possible in a single sheet metal part.

With respect to other plastics the preferred choice for long glass reinforced PP in door modules is based on the combination of:

- Excellent stiffness
- Excellent strength
  (Both properties at a wide temperature range)
- High dimensional stability and reproducibility

And all this at a relative low weight and low material price.
Further advantages for long glass fibre reinforced materials are:

- Low thermal expansion, reducing thermal deformations when in combined with steel structures.
- Excellent resistance to chemicals due to it's semi-crystalline nature.
- Good flowability. Despite the long glass fibres, flowability is much better than most people expect. This is due to the low viscosity PP grades that are used for the matrix. For short glass PP grades this would lead to brittle materials, but long glass grades obtain toughness by fibre length. The result is that in practise the clamp force never is a determining factor that influences the gating choice.

4. Mechanical design

Typical load cases governing the mechanical design of the door module carrier, are resulting from misuse of the door, see figure 6.

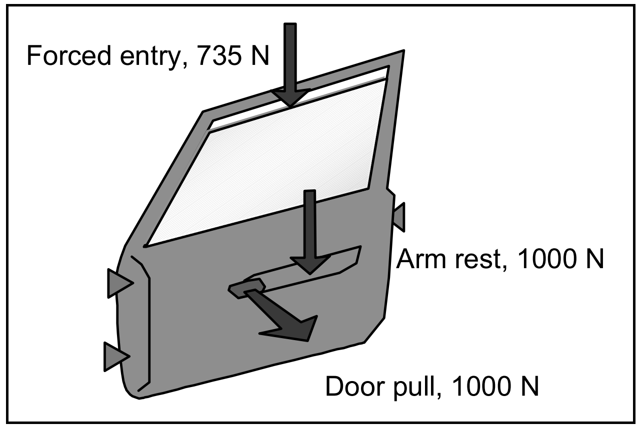

Figure 6, Typical load cases for door design

The forced entry case simulates someone trying to push the window down, against the window support attached to the door module.
The 1000 N arm rest and door pull case are typical ultimate force cases, at which there should be no failure. Of course there are further requirements, e.g. on repeated door pull or door slam, however at much lower load levels. Fatigue is then no issue for the long glass reinforced material.
The door pull case turned out to be the most critical for the new Ford Fiesta doors. The force is transferred by the composite panel to the metal door frame edges. Especially the metal edges showed high stresses, which necessitated design changes, see figure 7. In contrast, the stresses in the plastic part were very acceptable, and much below the allowable limit of 65 MPa. Also the deflection at the door grip was only 6 mm at the 1000 N load. See figure 8 for the high stress areas in the door panel.

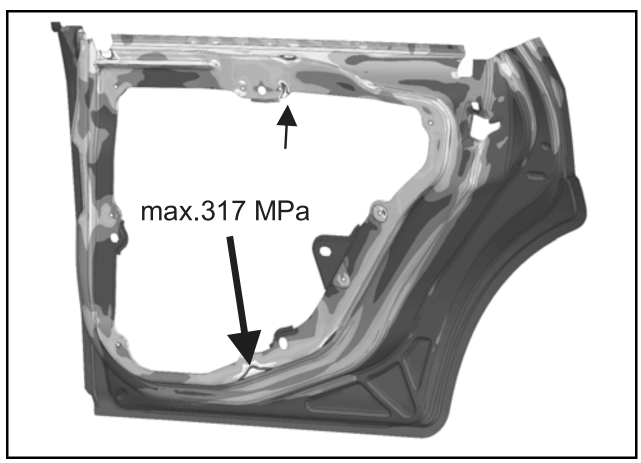

Figure 7, Stresses in metal inner door panel,
High stresses are light color gray.

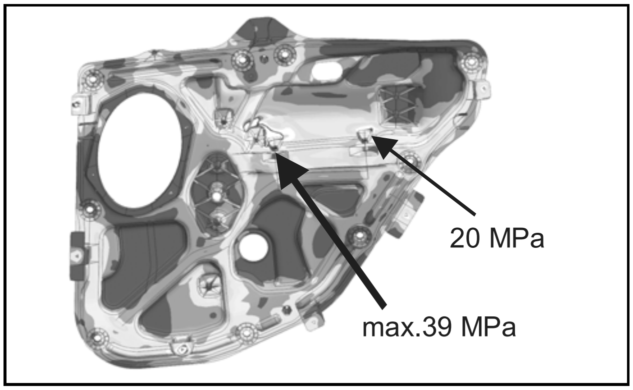

Figure 8, Stresses in StaMax door panel,
High stresses are light color gray.

5. Production design

For all glass filled materials material performance is dependent on fibre orientation, and even more important shrinkage is also not uniform due to this orientation. As a result the moulded part will show deviations with respect to the CAD-design. Especially flat parts are then sensitive to warpage.
In close co-operation between Faurecia, DSM, StaMax and the mouldmaker, extensive studies were done to guarantee a product that fits with all requirements. For this purpose many gating variants were studied, and the influence on warpage of the part evaluated, see e.g. figure 9, showing 2 gating variants. This evaluation was done both by simulation and by experiment. For the prototypes a 3-plate mould was used, which enabled easy changes of gating positions, to exactly match the simulation results.

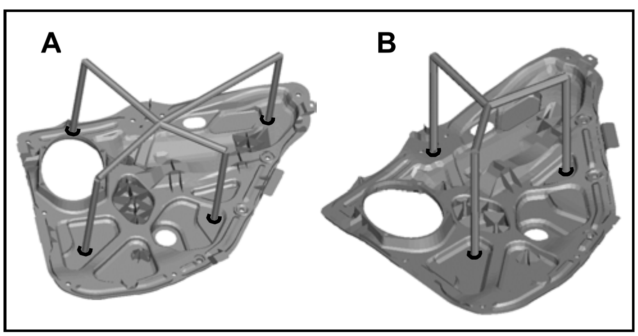

Figure 9, Two examples of gating variants

Filling of the part was simulated with a special (DADC adapted) version of C-MOLD mold-filling simulation software. Fibre orientation development due to the mould filling was calibrated on long glass fibre material, which shows a much lower amount of orientation than for short glass reinforced PP. Then real fibre and matrix properties were used to calculate the anisotropic mechanical properties, which were transferred with a DADC initiated interface to the MARC finite element mechanical analysis program. Using this program, warpage calculations were done, taking into account the real part fixation.
As the edge of the part has a sealing function, the out-of-plane deviations are important. Different gating systems will yield different shapes, as shown in figure 10.

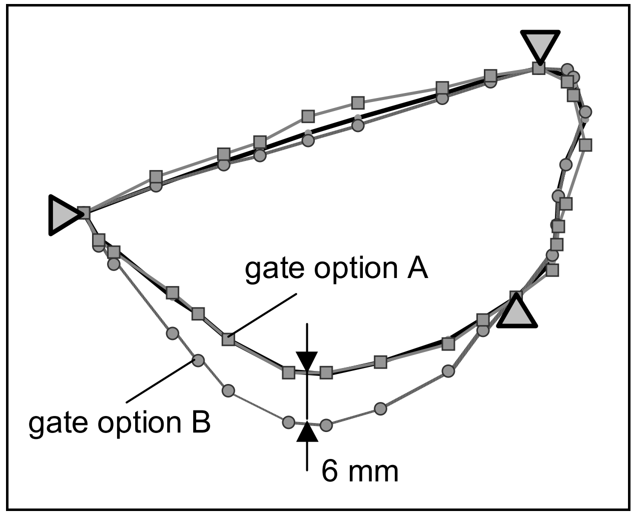

Figure 10, Edge deviation for gate options A and B (see fig.9), triangles show part support.

In the example of figure 10, gate option B shows significant more deformation as option A in the lower left corner of the part. It should be noted however that even today, warpage predictions cannot predict exact values. Only the direction of the warpage is in general O.K. Nevertheless the simulations show clearly the effect of changing the gating system. But even then one should consider the results with extreme care. E.g. in this example the module is fixed with 9 bolts to the metal surrounding. Clearly, fixing the edge with so many bolts will remove the warpage. To see if a part can be easily mounted, also an anisotropic mechanical assembly calculation was done. From this calculation the mounting forces per bolt location can be found, as is shown in figure 11.
In this case option B, which resulted in a part with more warpage, in reality shows easier mounting. This is caused by lower deviation at high stiffness areas, while the high deviation area shows low stiffness. In this low stiffness area the warpage will be easily removed by light pressure of the bolt.

This example shows that thorough knowledge and understanding of anisotropic mechanical properties and warpage is essential, to yield a good product.

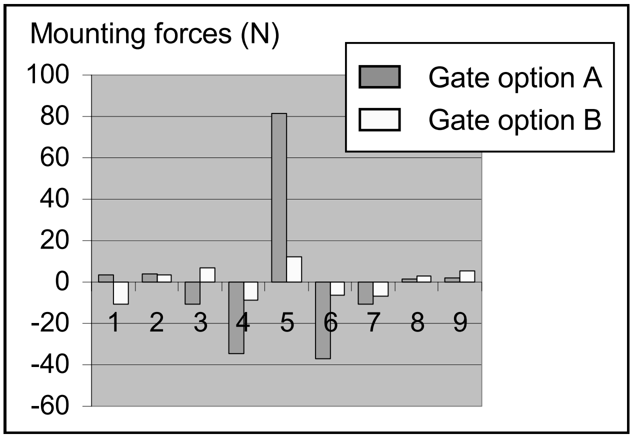

Figure 11, Bolt mounting forces for gate options A and B (see fig.9).

6. Dimension stability

In the previous section it was shown that depending on the choice of gating positions, some deviation from the CAD geometry may occur in the moulded product. This is typical for all glass filled materials, and most pronounced for short glass grades, as the level of orientation is higher there. This type of dimensional deviation should not be mixed up with the "dimensional stability". With dimensional stability it is meant that every part produced has exactly the same dimensions, and that these dimensions will not change in time or due to small changes in process conditions. Or in other words it is also called: dimensional reproducibility.
If all parts produced are almost exactly the same shape, it is possible to correct the mould for the deviations between part and CAD-geometry, to always yield a very accurate part, exactly conforming to the CAD-geometry.
As an example see some important length dimensions, measured between mounting holes on the forward door panel in figure 11. Even on a relative long dimension of 676 mm all measured dimensions stay within a tolerance band of ±0.06 mm. At such small values, it is even possible that the measurement accuracy is included in this band, and that the part tolerances are even tighter.

Even when extreme moulding process variations are taken into account, the tolerance band for the measured dimensions remains narrow, see figure 12. Note that due to the large variation in holding conditions the part weight varied between 820 and 900 grams. Such large variations would never be applied during real production. It shows however the robustness of the process, as even these extreme process variations, still result in a very reproducible part shape.

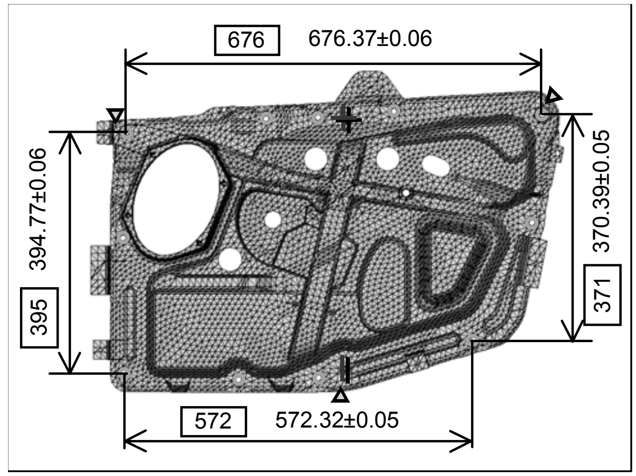

Figure 11, Measured dimensions on forward door proto-panel, one moulding condition, 16 parts,
CAD-dimensions shown in rectangles, measured dimensions showing max/min range.

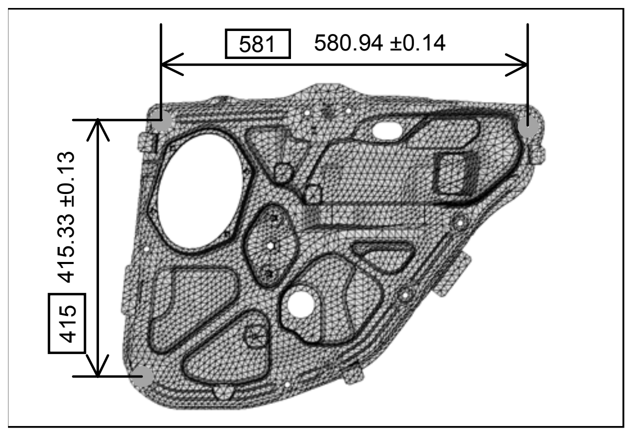

Figure 12, Measured dimensions on aft door panel, many moulding conditions, ranging from zero holding to 12 seconds, 45 bar oil, 35 panels measured.
CAD-dimensions shown in rectangles, measured dimensions showing max/min range.

7. New developments

At this moment most cars don't have door modules yet. As the advantages of door modules are there, many more will appear in time, and consequently further technical evolution will take place.
Some developments that are to be expected are:

- Higher level of integration
- 2 component moulding
- Hybrid material use
- Alternative production processes

The higher level of integration can be achieved by:
- increased functional integration
- an upgrade of the structural function of the door panel.

Starting with the increased function integration, have a look at the door module for the Ford Fiesta, shown in figure 3, were still a lot of metal parts can be seen. This means that still some separate parts can be integrated into one composite material part. It will also mean that all the functional components will have to be specially designed for the door module. E.g. the window regulator rail, with fixation brackets, could be integrated into the composite carrier. Clearly the window regulator system should be supplied then in a different form. Also, for the current Ford Fiesta model, the lock module is supplied as a separate item, and then fixed to the door module. This has to do with OEM decisions to buy certain parts at certain suppliers. It would be far more logical in the future to integrate the lock module into the door module. Fit and tolerance problems would be greatly reduced.
More advanced options would include the metal speaker housing, which could equally well be moulded in rigid plastic directly as part of the composite module. Also then the speaker should be supplied in a different reduced form and also fixed differently, especially the speaker membrane. Although this may sound difficult, it will also generate new design options. Similar considerations can be made for all attached components, such as the window regulator motor, whose housing could be part of the door module.
Electronic cable assemblies can be directly overmoulded, and as such protected against (intentional) damage. Electronic components will have to use plug connections and thus be specially designed for advanced door modules. Most important, the protected cable assembly will be a significant quality improvement, and also make assembly easier.

Apart from functional integration, also increased structural function integration is to be expected for future door modules. The first logical step is the integration with the trim panel, as one optimised designed unit, see figure 12. By a better structural design of the door module panel, the trim can be reduced to a much lighter component with a mainly visual or soft-touch function.
More advanced, the load carrying function of the metal door structure can be taken over by a structural door panel. Hinges will stay in metal. And most probably the rail containing the window rubbers also. Such concepts have been demonstrated already in demonstration projects, such as the Brite-Euram Plasmat door demonstrator.

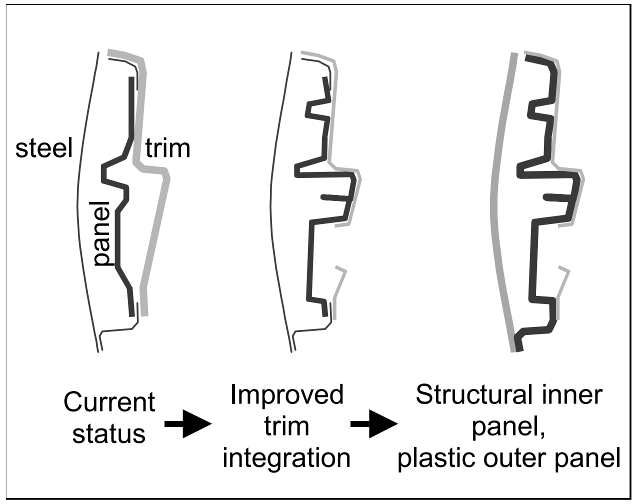

Figure 12, Door section, structural upgrade development steps.

Advantages of a near full plastic door obviously lay in the area of increased corrosion resistance, lower weight, and increased design and assembly options. Increasing demands on crash impact safety will necessitate the use of either steel reinforcements or continuous fibre reinforced plastic inserts. Hybrid glass/PP fabric inserts, such as Twintex material, are well known. However also materials with unsurpassed impact protection properties such as Dyneema ultra-high strength Polyethelene fibre material, can be overmoulded with long glass PP. See e.g. figure 13, showing an 60x60mm impact specimen, cut from a plate, one sided overmoulded with StaMax P material. Penetration resistance was improved dramatically.

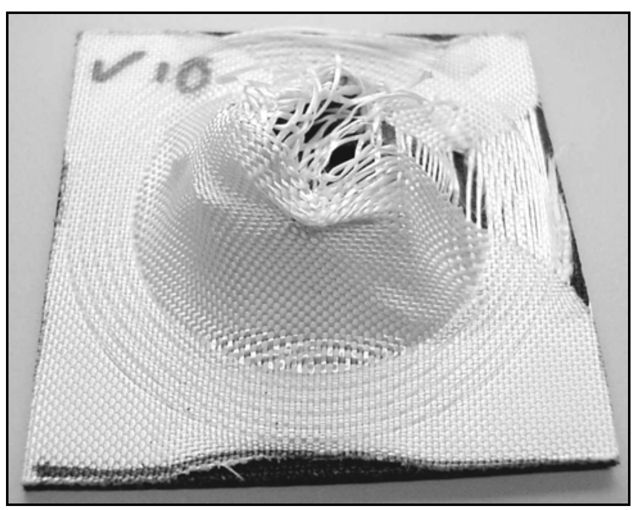

Figure 13, Hybrid StaMax-Dyneema impact specimen.

From the production process side also innovations are to come. An obvious step is the use of 2-component moulding. Rubber seals, e.g. from Sarlink, can be overmoulded onto a StaMax carrier, yielding a thorough reliable fixed seal. The function of this second material doesn't need to be limited to this seal, e.g. also soft-touch storage pockets can be integrated into the door panel.

Especially for long glass PP materials there are also other interesting production processes. One of them is injection compression moulding, which due to the more gentle process yields longer fibres in the product. These longer fibres will then result in even better impact properties. More interesting for door modules may be the relative low mould pressures, present during the moulding. It makes overmoulding of cable harnesses easier, and opens possibilities for semi-visual parts without sinkmarks.
A further advantage of injection compression moulding, is that with clever gating strategy it is much easier to make weldline-free parts. And of course this will help in controlling any warpage.

For the future, it can be summarised that we are just at the beginning of the development of door modules, and that for certain many new developments will take place.

8. CONCLUSIONS

1. In close co-operation between Ford, Faurecia, StaMax and DSM, composite doormodules were successfully introduced for the new Ford Fiesta.
2. The use of doormodules will in general yield:
   - an overall quality improvement
   - a significant weight saving over a metal module
3. Cost savings may be difficult to prove, although assembly advantages are clear. Moreover, in future many more exiting integration possibilities exist.

9. REFERENCES

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Acknowledgements

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