Practical application of thermoplastic composites for body-in-white application development: A collaborative approach between DuPont and Renault

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Abstract

The Renault EOLAB prototype is a showcase for many lightweighting innovations. Key among them is the extensive use of thermoplastic composites (TPCs) for important structural components. DuPont™ Vizilon™ TPCs are used for the large structural floor pan, lower and upper windshield cross members and B-pillar, which together are nearly 25kg lighter than the metal parts they replace. These components have been developed by Renault and several parts suppliers, in close collaboration with DuPont.

Lightweighting, which improves fuel economy and reduces CO₂ emissions, has been identified by the auto industry as one of the primary ways to meet new and emerging global emissions and fuel economy standards. The success of EOLAB as a showcase for the future lightweight car is also proof that Vizilon™ TPC can replace metal in many structural parts, and offer practical and affordable opportunities for significant lightweighting.
DuPont has developed high-speed in-house material testing capabilities to help automotive players make a confident transition from metals to TPCs, and to demonstrate outstanding TPC performance supported by high-quality material data.

Introduction

Increasingly strict CO₂ emissions regulations up to 2020 are forcing the auto industry to take into account all the technological levers that enable reductions in the carbon footprint. Those levers are power train efficiency, weight reduction, architecture and aerodynamic optimization, and reduced friction losses.

At Renault, our target is 20% weight reduction, representing two inertia classes in reference to current vehicles. For several years already, the company has deployed many action plans to reduce weight. The steel grades on body in white have been changed from mild steel to high, very high strength or ultra high strength steels (VHS, VHSS, UHSS). In 10 years, the use of such steels has increased by over 50%. In addition, aluminum and plastic materials have been implemented for parts such as hoods.

To go beyond 100 kg weight savings, we must:

- make intensive use of high strength steels (but it will not be sufficient)
- increase the quantity of aluminum, magnesium or plastic parts
- add new materials such as composites. They could be suitable for several applications such as structural parts.

“Composites” is a generic name — we can find many types of composites offering a diversity of technical solutions through particular choices of polymers (thermo set or thermoplastic), and with carbon or glass fibers of different lengths (short, long, continuous) and different forms (unidirectional, woven, etc.).

These new materials must answer all the technical and industrial requirements of the automotive industry, including numerical product/process design, cost effectiveness, compatibility with existing industrial facilities, and high production volumes.

Moreover, these new materials must fulfill potential new regulations, e.g. for VOC, odor, recyclability — regulations that may have a deep impact on resin and fiber technology.

1. Why thermoplastic composites for EOLAB?

Thermoplastic composites (TPCs) are at an advanced stage of development and now compete with metals in structural automotive parts. TPCs have undergone a step change in properties compared with standard thermoplastics — particularly in strength and stiffness — that now enable direct metal replacement in many applications.
Fig 1: Vizilon™ components in the Renault EOLAB shown in yellow, are nearly 25kgs lighter than the equivalent parts in metal.

TPCs offer opportunities for significant lightweighting unmatched by metals. This is particularly important since weight reduction is one of the key solutions available today to reduce CO₂ emissions in vehicles.

Increasing familiarity with TPCs is encouraging engineers to design for these stable, non-isotropic and complex materials. Even engineers and designers who know metals well are gaining in confidence in how to get the best out of TPCs. EOLAB has given Renault, Faurecia, Plastic Omnium and DuPont the freedom to work with these remarkable materials, and to prove that we can make TPCs work in automotive.

However, the most effective way to reduce weight is to design for TPC first, rather than using TPC in parts designed for metal. This requires a different approach and new material data, but helps ensure that all the lightweighting, strength and functional benefits of the material are captured.

**EOLAB and DuPont™ Vizilon™ TPC**

Close collaboration between DuPont, Renault and high-tech composite specialist suppliers on the EOLAB project is based on DuPont™ Vizilon™ TPC — a technology that combines strength and stiffness in a lightweight structure to help automakers replace metal and reduce
weight in structural applications.

Vizilon™ TPC sheet delivers weight savings with an ease of manufacture that is competitive with metals processing. But it also offers opportunities for functional integration, reduction in the number of parts and lower tooling investments that are difficult to match in metal. Based on appropriate design, Vizilon™ can also compete with metals for stiffness.

**Light strong TPC floor pan replaces steel**

Although there are many applications with high potential for Vizilon™ lightweighting solutions in EOLAB, including B-pillars and lower and upper cross members, this presentation will focus mainly on the floor pan, the largest single TPC component in the Renault prototype, but also features the lower windshield structural body cross-member (see section 3. The challenge of EOLAB).

Working in close collaboration with DuPont, Faurecia engineers have developed an integral structural floor comprising a front and rear passenger floor and a trunk floor made of glass fiber reinforced Vizilon™ TPC formed using "thermostamping" techniques. Faurecia has also incorporated acoustic components into the empty space between the upper and lower layers of the thermoplastic structure to muffle noise.

*Fig 2: Vizilon™ TPC floor pan is 16.5 kg lighter than a conventional steel vehicle floor, offers outstanding mechanical performance and enables integration of welded and over-molded parts. (Photo: Courtesy of Faurecia).*

In addition to offering outstanding mechanical performance to meet crash-test requirements and ensure recyclability, the TPC floor pan also enables the integration of welded and over-molded parts. This technology reduces weight and cost compared with bonding while producing a material able to withstand the very high temperatures created during e-coating (cataphoresis).

The TPC floor pan is 16.5 kg lighter than a conventional steel floor, reducing CO₂ emissions by about one and a half grams per kilometer. It achieves the 33% weight saving goal set by Renault for its EOLAB concept, and could enter production four or five years from now.
TPC lightweighting solutions

Key lightweighting solutions provided by Vizilon™ TPC are:

- Superior weight-specific strength versus metal parts
- Excellent energy absorption for impact/crash components
- More complex part design possible than with metals
- Superior long-term heat ageing
- Little variation in part stiffness from -40°C to 90°C
- High damping coefficient, improved NVH
- No corrosion treatment necessary
- Compatible with e-coat process
- Produced as a continuous fiber sheet optimized for processing and performance
- Recyclable.

1.1 Material characteristics, weight specific properties

DuPont Vizilon™ TPC sheet products, based on PA66 polyamide, offer simple glass architecture for fast impregnation, strength and stiffness, easy processing during laminate thermostamping, and good healing with over-molding resin for a wide processing window. They are also fully characterized for predictive engineering including crash simulation.

Fig.3: In the Vizilon™ TPC concept, DuPont combines sheet and overmolding to produce complex hybrid parts that can replace metal at significantly lower weight.

On a weight-specific strength basis TPCs are much stronger per kg than metals (see Fig 4.) combining lightness with strength unmatched even by ultra high strength steel.
Fig 4: Vizilon™ TPC exhibits superior strength than ultra high strength steel and aluminum on a strength per kilogram basis, combining lightness with strength unmatched by metals.

The weight-specific stiffness of Vizilon™ TPC approaches that of steel (see Fig.5.) — a characteristic that presents new opportunities to design with the material to achieve equivalent stiffness to metals. It has not been possible to achieve this with standard short fiber polymers and still benefit from weight savings.

Fig. 5: Vizilon™ TPC exhibits stiffness approaching that of steel on a per kg basis, presenting new opportunities to design with the material to achieve equivalent stiffness to metals.

These tests were based on Vizilon™ SB63G1 sheet, a fast impregnating black heat stabilized polyamide 66-based structural thermoplastic composite comprising 2-2 twill weave glass fiber reinforcement — and on Vizilon™ SU75G1 sheet, a high glass content black heat stabilized polyamide 66-based structural thermoplastic composite comprising 4/1 plain weave glass fiber reinforcement.
Both are functionalized for easy processing, maximum in-use performance, and improved interfacial bonding during overmolding and welding processes, with excellent heat ageing resistance.

1.2 Crash performance

There is a perception that composites are brittle and therefore unsuitable for parts such as side intrusion beams in door structures subject to extensive deformation in the event of a side impact. This is not so. Images from DuPont drop tower impact testing on a Vizilon™ beam (see Fig. 6) show that a properly designed beam structure can resist as much deformation as a steel beam without breaking. In addition, as energy absorption uses a different mechanism than the “traditional plasticity” of metals, the beam will show less permanent deformation after impact than a steel beam.

![Drop tower impact test on a stamped Vizilon™ TPC sheet beam involving an impact mass of 16kg at an impact speed of 10m/s shows that a properly designed beam structure can resist as much deformation as a steel beam without breaking, and exhibits excellent recovery and less permanent deformation after impact.](image)

1.3 Dimensional stability / e-coat capability

Vizilon™ has a coefficient of thermal expansion almost identical to steel. This enables good control of gap closures and assembly tolerances, and predictable behavior under e-coat temperatures in close proximity with metals, without galvanic corrosion. Vizilon™ withstands e-coat paint drying temperatures, typically around 200°C for 30 minutes, although this is beyond the temperature capabilities of many plastics.
1.4 Functional integration through overmolding or welding

TPCs can be designed for overmolding and welding to add functionality or steel inserts. Applications that today comprise several steel sub-assemblies can now be integrated during overmolding, resulting in fewer parts, and lower tooling and processing cost. This cannot be achieved with metals. TPCs are also compatible with other injection or compression molded thermoplastics for added design and process flexibility.

1.5 Recycling

TPCs can be reground on site unlike metals and thermosets, and scrap can be reused directly. Stamping waste can be completely recycled and used as an overmolding material to integrate functions.

2. Process development, testing and prototyping

DuPont has the ability to combine different Vizilon™ sheet products in different ways to maximize processing flexibility and end-use performance (see Fig. 8).
Combining materials for processing flexibility

DuPont Vizilon™ TPC technology is supported by an approach in which design, materials and processing all work together to take out weight. We use advanced FEA (finite element analysis) methodology and CAE analysis to support part design and predict part performance — the key to successful commercialization.

2.1 Prototyping machines and tools

Vizilon™ TPC sheets and overmolding resins have been designed to work with all TPC processing options. In addition, process cycle times for TPC are very short, normally around 60 seconds or less, and match typical automotive mass production cycle times.

At the DuPont European Technical Centre (ETC) we have three work cells with capabilities for stamping, trim and preparation, and overmolding:
2.2 Material characterization / data cards

DuPont offers a unique and extensive materials data package to help the customer. The company is a leader in materials testing using FEA analysis and is unusual in operating a digital correlation system employing high-speed cameras.

We work closely with the automotive industry on process, material and simulation until start of production. Customers are also able to perform independent analysis using DuPont material data cards showing the objective behavior of Vizilon™ TPC in all loading conditions including high-speed crash. Essential material characterization includes, for example, stress-strain curves, tension, compression and shear, and thermal testing from -40°C to over 120°C.

In addition to testing facilities at ETC, DuPont operates a large central engineering test laboratory in the USA. Within the DuET (DuPont Engineering Technologies) program at this site, the company tests materials and parts from static to crash.
Fig. 10: DuPont carries out high-speed specimen testing of Vizilon™ sheet using 60g custom made grips, providing 5 MHz 8-channel longitudinal and transverse strain measurement data.

3 The challenge of EOLAB – how to overcome the obstacles

3.1 TPC versus metals — opportunities for part integration and design breakthrough

By understanding the application and designing for EOLAB, Faurecia engineers were able to reduce the number of floor pan parts by more than 50%. This was achieved by integrating seat and safety belt anchorage points and the rear seat bench folding system via overmolding of these parts onto the double-shell base, thus optimizing processes, improving cycle time and quality, and reducing side-costs. Such a degree of part integration is not possible with aluminum and other metals.

The lower windshield structural cross-beam also uses a double-shell closed section design, enabling it to save more than 50% weight over the steel incumbent. Thanks to this specific “box-design”, the torsional stiffness of the part has been increased by 500% and flexural stiffness by 150% thus providing a clear advantage in overall body torsional stiffness.

Furthermore, overmolding a specific short-glass fibre Vizilon™ polyamide 66 enabled the addition of functionalities including the wiper motor support, the water-gutters, the HVAC inlet and also the bonnet grommet (joint) groove. The overall number of parts was reduced from 10 to 6 compared to metal.
Fig.11: The double-shell design of the lower windshield structural cross-beam enables savings of more than 50% in weight, a 500% increase in torsional stiffness, and a 150% increase in flexural stiffness over the steel incumbent.

Vizilon™ TPC sheet can also be welded in a similar way and cycle time as metal but with the added advantage of a quieter, spark free process.

3.2 Energy absorption and NVH

Acoustic components have been incorporated into the space between the upper and lower double shell layers of the Vizilon™ floor pan design to muffle noise and harshness, improve acoustics and dampen vibration. This structure also possesses excellent energy absorption characteristics as a result of its hollow section design combined with the exceptional strength of Vizilon™ TPCs.

4. Summary and Outlook

Lightweighting, which improves fuel economy and reduces CO₂ emissions, has been identified by the auto industry as one of the primary ways to meet new and emerging global emissions and fuel economy standards. The industry also acknowledges that replacement of metal parts with TPCs will play an increasing role in this endeavor in future.

Renault’s EOLAB prototype uses TPC materials extensively to help make the vehicle 400Kg lighter than that of a B-segment hatchback like the Clio IV. EOLAB is proof that TPC structures provide a cost effective, affordable and high performance replacement of heavier metals.

TPC is intrinsically light with a specific gravity of 1.8 to 2g/cm³, compared to steel with a specific gravity of 8g/cm³. This enables the Vizilon™ floor pan to save an impressive 16.5Kg of weight versus the steel equivalent. All Vizilon™ components in EOLAB save a total of nearly 25Kg.
The advantages of TPC structures do not stop there. TPCs offer superior weight-specific strength versus metal parts, and enable more complex part design and functional integration. Their excellent energy absorption characteristics make them ideal candidates for impact/crash components. Parts exhibit little variation in stiffness over a wide temperature range from -40°C to 90°C and offer superior long-term heat ageing. They are compatible with the e-coat process and are not affected by galvanic corrosion. TPC sheet products are fully recyclable in production and at end of life.

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