The Designers Guide to Composites for Mass-Produced Vehicles

Leveraging an end-to-end solution for Design, Analysis and Manufacturing

DESKTOP ENGINEERING

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Introduction

The growth of automotive composites applications has historically been hampered by a number of technical issues, including relatively long processing times, difficulties in assigning the right material properties, and high material costs. Today, rapid progress is being made on these issues and original equipment manufacturers (OEMs) are using composites in production vehicles to reduce vehicle weight, improve fuel economy and reduce vehicle emissions. Now more than ever, OEMs are on the verge of incorporating composites as a strategic aspect of their business for both structural and non-structural components. Moving forward, the automotive industry needs a complete end-to-end solution to address the specific challenges of designing, analyzing and manufacturing automotive composites vehicles and enable automotive OEMs, as well as suppliers, to implement a seamless process to develop high-quality composites designs and bring them to market faster and at a lower cost.

Composites on the Rise

Over the last 30 years, the use of composites in the automotive sector has significantly grown to extend well beyond its original applications. Starting in the 1980s, most of the Formula 1 racing car chassis –the monocoque, suspension, wings and engine cover – have been built with carbon fiber composites. In parallel, the Pontiac Fiero became the first high-volume composite-bodied car in 1983 and in 1992 the Dodge Viper was introduced with many composite parts. The application of composites has also been extended to luxury and premium vehicles such as Lamborghini, Tesla, Ferrari and others for low volume production.

Today, composites are making major inroads in premium cars and beginning to infiltrate the mass market. Composites are utilized in well over 100 components on current model vehicles ranging from the grill opening panel of the Ford Crown Victoria, the door panel of the Cadillac Escalade, fenders of the Mercury Mountaineer, the pickup box of the Toyota Tacoma and the front fascia of the Dodge Charger.

One of the primary reasons why automobile OEMs are turning to composites more massively is their ability to reduce weight and consequently improve fuel economy. The BMW Megacity Vehicle is a good example. With its introduction, planned for 2013, the BMW Group will be launching a volume-production vehicle on the market that features carbon fiber-reinforced material.

Compelling Benefits

The Automotive Composites Alliance (ACA) recently benchmarked a prototype sedan to identify the weight savings that could be achieved by converting metal components to composites. A one-piece composite molding can replace six to eight metal stampings in the trunk compartment while reducing mass by up to 50%. A composite hood can provide a 30 to 40% savings in weight compared to a steel hood. Weight can be reduced 25% to 35% by consolidating four metal parts into a two-piece composite deck lid assembly. Hybrid fenders combine four parts into one for 25% to 35% mass reduction[1].

But the benefits of composites go far beyond weight savings. Tooling for composite parts can be as little as 20% of the cost of tooling for comparable metal parts. Lower composite investment costs satisfy automakers' desire to achieve reduced builds per model. Fiber reinforced polymer composites make it possible to design assemblies with fewer parts, resulting in lower manufacturing costs and faster time to market. Composites are much more resistant to damage such as dents and dings than aluminum, steel or thermoplastics. Their resistance to corrosion is also much better than for metal parts. Superior internal damping of composites provides improved noise, vibration and harshness (NVH) properties. Composites also enable a level of shape flexibility, geometrical details and depth-of-draw range far beyond what can be achieved with metal stampings.

1- http://www.autocomposites.org/news/advertorials/2008.pdf

Manufacturers of mass transportation vehicles – including passenger rail trains and trams, buses and coaches – are also greatly increasing their use of composites. Low weight composite materials reduce energy consumption, reduce emissions and allow existing tracks to be used for new high speed and tilting trains. Composites provide additional energy and emissions savings by making it practical to use more aerodynamic vehicle exteriors. Structural composites require little supporting framework, which increases vehicle payload space. Composites also can be engineered to provide energy-absorbing and fire-resistant properties that improve vehicle safety.

From Metal to Composites: Facing News Challenges

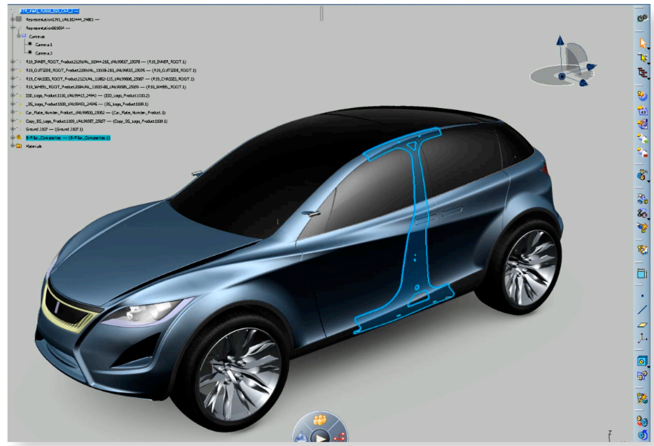
Success in utilizing composites structures in automotive requires substantial improvements in the tools used for the end-to-end process, from product design and virtual testing to manufacturing. Most existing computer aided design (CAD) software solutions are originally intended for use with metal and plastic parts of far less complexity than today's multi-layered composites. They offer no facility for keeping track of the laminate and composites properties, forcing the engineer to track this information manually in a spreadsheet.

From a simulation perspective, evaluating the mechanical performance of the proposed design is challenging because ply and composites parameters must normally be manually re-entered in the finite element analysis (FEA) software, a time-consuming and error-prone process. The design typically goes back and forth multiple times between the engineer and analyst while being manually tracked via spreadsheets, further increasing the risk of errors. Another problem is that most of today's finite element software is designed for metallic materials like steel and aluminum that yield, bend and fold when they fail compared to composites, which on the other hand crack, fracture and delaminate.

When it comes to manufacturing, the complex shape of automotive body geometries makes it difficult to predict how composite materials will conform to the molds complex surface. A major hurdle lies in developing flat patterns that will meet the ply guidelines without fabric distortion, such as bunching up on the mold or exceeding material tolerance.

The prevalent procedure is to cut fabric plies by hand and try to fit them on the mold tool. The entire test article process is typically very long and uses substantial amounts of expensive composite materials. This manual process can also lead to costly errors in the positioning of the plies on the mold.

Currently, composites process planning does not take advantage of the product definition that is embedded in the model by the designer. Typically, composites process plans are created using manual entry or finite element mesh defining plies in a quick way for rapid development that does not match the as-built models. Invalid work instructions and planning sequences, as well as the inability to quickly analyze the impact of design changes on manufacturing processes further extend the time needed to deliver the product.


Example of structural component designed and manufactured with composites materials

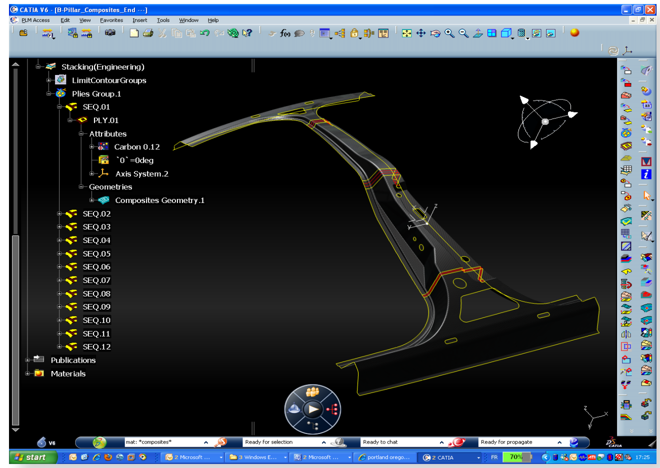
Clearly, designing and mass-producing complex production-ready automotive composites parts are highly complex and expensive. Traditional software solutions cover the design, analysis, and manufacturing of composites parts in a sequential, time-consuming, non-collaborative process burdened by heavily manual operations.

To meet these complex challenges, Dassault Systèmes (DS) has continuously been working in close collaboration with major industry leaders to develop end-to-end PLM solutions to design, simulate, and manufacture composites structures on a single platform. At the heart of the Dassault Systèmes composites solutions, CATIA provides a dedicated environment for the design of composite parts and structures, SIMULIA provides advanced simulation tools and composites-specific methodologies to improve the design, increase the value of virtual testing, and significantly reduce the reliance on physical testing while meeting regulatory requirements, and DELMIA supplies digital manufacturing capabilities from planning to simulation-based validation, work instruction authoring, and actual delivery to the shop floor.

A Complex Design Process

When it comes to car design, the automotive industry has been mastering mainly metals which are considered isotropic materials. Composites materials are not isotropic. Their numerical definition is complex and involves many different parameters. As a result, when modeling composites parts, one of the challenges lies in finding the right balance between the number of parameters necessary to characterize the material accurately and the computation time needed to take all those parameters into account. To address this requirement, Dassault Systèmes' CATIA Composites solution provides accurate characterization based on material property data that allows engineers to easily and quickly define a detailed composite lay-up.

Another key design challenge is the necessity to quickly explore and test many different variants in the preliminary design phase. What is critical at this stage is the ability to create and update the composites models within hours of a design change. CATIA Composites solutions offer various methods including Zone, Grid and Solid Slicing for the automatic creation of plies, and provide associativity between surface and composites parameters. When the interior or exterior surfaces change, it is important the update be made directly within the design environment rather than having to import new surfaces and rebuild the solid model. The composite model is automatically updated based on the new surfaces, enabling significant time savings. This approach also ensures a higher level of accuracy that reduces the number of physical prototypes needed to finalize the design.



Automatic ply creation with Zone-based approach

It is also necessary for designers to be able to perform analysis on the composites parts early in the process with a clear idea of the foams, fabrics, fiber reinforced materials, and so forth, in order to understand the behavior of the various materials involved and their mutual interaction. CATIA Composites solutions deliver a comprehensive set of composites inspection tools (core sample and numerical analysis, interactive ply table, etc.) to review the composites structure in detail.

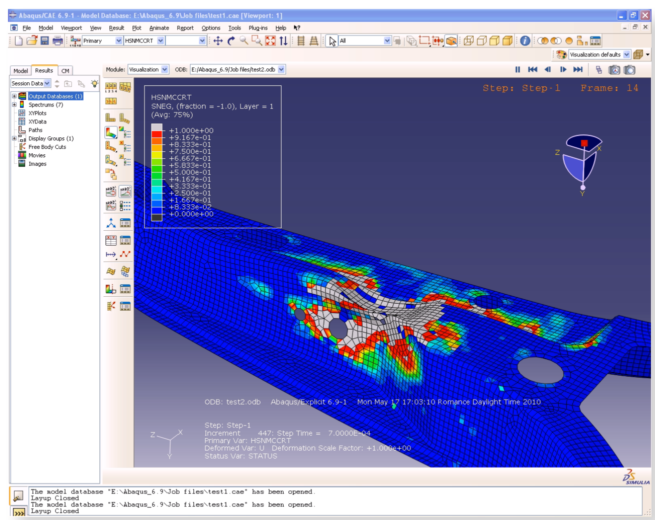
In order to achieve design weight and strength optimization, as well as ensure the final product performs as designed, it is necessary to be able to integrate the design, analysis and manufacturing process on a single platform. Automotive metals part assemblies are joined either by welding, rivets, bolts or bonding. For composites the assembly process can be quite different. Designers need to clearly understand the composites material properties and the manufacturing assembly process, as well as the potential impact these could have on the parts they are modeling. With CATIA Composites, productive features are provided to enable the designer to integrate the manufacturing constraints early in the design phase and take them into account when modeling the parts.

Last but not least, during the design phase, designers need to be able to simulate the manufacturing process in order to visualize the fiber orientation of the material on the shop floor. Without this capability there will be a big difference between the final product and the design intent, resulting in poor quality and delays in production. DS leverages its network of highly qualified technology partners to provide advanced specialized applications, fully integrated to the CATIA Composites design environment, to simulate ply behavior and evaluate fiber deformation. Corrections can then be made before the design is sent to the shop floor for cutting and hand lay-up. Engineers can visualize the ply stacking and tweak the laminate structure to eliminate wrinkles and other issues before the design is sent to manufacturing.

Properties and Crash Simulation

As mentioned earlier, composites materials are heterogeneous and their behavior is therefore, more complex to comprehend and predict than metals. It makes it all the more critical to have powerful and reliable simulation applications to understand how the part being designed will behave. Today, the main challenge is to utilize the appropriate simulation application on the one hand, and to take full advantage of composites material properties on the other hand. As the automotive industry is still in the early stages of composites parts mass production, raw materials manufacturers are constantly coming up with new materials for which the parameters need to be established. Relying on partner products fully integrated in the design environment, Dassault Systèmes provides the knowledge and the skill to quickly define the complete properties of a new material and drape this new material on its final shape.

The loss of information and the time required to transfer composites data between CAD and Computer Aided Engineering (CAE) applications, often requires data translation, and is another major concern today. The integration of the CATIA Composites design information with SIMULIA Abaqus/CAE FEA software overcomes these issues. The ability to directly transfer accurate fiber angles and ply thicknesses from the design to the analysis environment improves the simulation accuracy. Transferring updated design information from analysis seamlessly back to design enables designers and analysts to work closely together, ensures the analyzed model matches the final structure, and prevents the specification of plies and structures that cannot be manufactured. Simulation specialists are familiar with metal parts but the study of composites assemblies' failure requires a comprehensive analysis of crack propagation, delamination, crash worthiness, crush and many other severe events inherent to composites. To analyze and simulate these, Dassault Systèmes SIMULIA Abaqus finite element analysis software provides powerful capabilities based on specific technique and technology such as Virtual Crack Closure Technique (VCCT) for Delamination or CZONE technology for direct implementation of crush-based element force generation and failure in defined "crush zones".



Progressive impact simulation on composites B-pillar

From Manual to Automated Manufacturing Processes

The automotive industry currently produces high volumes of metals parts. It is a major challenge for OEM's and Tier Suppliers to shift to producing high volumes of composites structures. The high cost of raw material as well as the lack of automated and repeatable manufacturing processes are preventing composites from being widely used in automotive mass production. DS DELMIA Composites Planning solution takes advantage of the ply stacking and composites properties from the CATIA model to deliver comprehensive process planning and documentation capabilities to automate manufacturing processes to author the process plan and work instructions. In addition, Dassault Systèmes has partnerships with the leading machine tool manufacturers in an effort to address various shop floor systems for automated fiber placement and tape laying systems. Dassault Systèmes also offers DELMIA Robotics solution to facilitate automation of the composites production lines.

The selection of the manufacturing process depends on the production volume. Whereas for low volumes a manual process is recommended, for medium to high volumes, an automated process is more suitable. With manual lay-up, automotive manufacturers are reaching a quality limit because it is very difficult to predict the exact final finish of a part on the shop floor. The operator may not deposit the ply always at the same position which jeopardizes the effort of the precise initial design. Then, to help the operator to accurately lay the fabrics on the mold, Dassault Systèmes leverages best-in-class industry solutions - fully integrated in the design environment - for nesting, cutting, and laser projections systems, which facilitate optimizing ply lay-up of a composites model with the highest degree of accuracy.

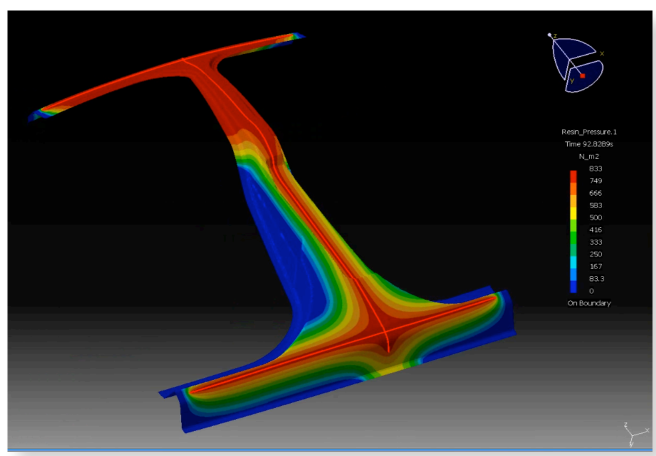
While additional progress still needs to be made in order to move composites into more large-scale production applications, a key factor in the advance of composites in transportation has been continuous improvements in manufacturing processes, such as Resin Transfer Molding (RTM), that are well suited for large-volume automotive applications. RTM is a closed mold process, where dry fiber material is placed between two mold surfaces and resin is injected to fill the voices. RTM has seen significant interest in recent years because the use of a closed mold makes it easier to meet tighter environmental regulations. RTM also makes it easier to maintain the product quality that is suitable for automation and makes it possible to achieve good tolerances, excellent mechanical properties and superior surface finish. Typical high tooling costs have been reduced through the use of vacuum in balance with the injection pressure.

In this regard, DS provides a complete solution for simulating and optimizing the RTM process, through partner's products. It enables engineers to locate injection gates and vents to avoid dry spots, predict and optimize filling and curing times, calculate the pressure in the mold during injection and find the velocity of the flow upfront to prevent fiber displacement.

Conclusion

The automobile industry is increasing its use of carbon fiber reinforced composites for a wide range of applications from panels to more complex structural parts in racing, luxury, premium and mass produced vehicles to meet fuel economy regulations and achieve a number of other key benefits. The traditional manual, sequential, and trial-and-error-based composites design process makes it difficult to take full advantage of composites' tremendous performance capabilities due to long product development cycles and inexact manufacturing processes.

As the leading provider of PLM solutions for worldwide automotive OEMs and their suppliers, Dassault Systèmes has long been the leader in providing tools to meet the special requirements of the automobile industry. Now with its end-to-end solution for composites, DS provides to automotive OEMs and suppliers a unique integrated platform with specialized CATIA, SIMULIA, DELMIA and technology partners' solutions, which allows them to reduce their time to market and avoid costly errors while minimizing vehicle weight and cost.



RTM resin flow simulation

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