DESIGNING WITH THERMOSET COMPOSITES: A SURVEY OF RESOURCES AND TOOLS

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Abstract

Automotive OEMs cite the difficulty in modeling composites as a significant barrier to their wider use. Unlike metals whose properties are isotropic, composites have behavior that may be more difficult to model and to predict. Accurate materials characterization is increasingly important in allowing engineers to create the most cost-effective and reliable designs. In addition, as carmakers make greater use of computer-aided tools, detailed characterization becomes a basic requirement to consider a material for a particular application.

This paper surveys some of the tools available for optimizing high volume automotive designs in thermoset composites, namely sheet molding compound (SMC), and describes the range of resources from qualitative design guides to quantitative prediction models.

Background

The history of thermoset composites dates back centuries to the use of mud bricks reinforced with straw to build some of man's oldest known structures. The earliest automobiles were built using a type of composite, wood laminates, covered with steel sheet. Eventually, the entire body and frame of the automobile were made from steel as manufacturing processes for metals improved [1]. Discoveries, manufacturing techniques and applications for metals, especially steel and aluminum, progressed faster than those for polymers materials. It was not until the mid-1940s that the modern science of composites began to take hold [2]. By this point, however, steel and aluminum had become well established as the norm for automotive design. Steel was reliable and relatively inexpensive. Huge capital investments further motivated carmakers to continue to use steel rather than to experiment with new technologies.

By the mid-1980s, the advent of the computer workstation and rapid advances in computing power were beginning to allow automakers to "digitize" their designs. Soon to follow were software packages able to do basic finite element modeling (FEM). These packages were able to compute static loading, strength of materials, and perform iterative design assessments. A vast database of steel and aluminum properties already existed in the literature. Standard grades had also been created. Together, these provided engineers the necessary tools from which to create designs quickly and accurately.

Designing with composites, on the other hand, did not progress as fast. Composite design is more complicated than steel for three main reasons: 1) unlike standard grades of metal, each combination of resins, reinforcements and additives can yield unique performance characteristics, 2) composites have inherently non-isotropic behavior (sometimes a benefit when designing for strength in a specific direction), and 3) stress-strain characteristics for composites are frequently non-linear. Fortunately, these challenges are being overcome by first following sound design practices, then using software tools to make refinements.

Design Manuals for Thermoset Composites

The Automotive Composites Alliance (ACA) [3], a division of the American Composite Manufacturers Association (ACMA), publishes several guides for the design of thermoset composite parts namely those made using the sheet molding compound (SMC) process. SMC is the most common process for thermoset composite automotive parts. Other common processes include bulk molding compound (BMC) and structural reaction injection molding (SRIM). Available ACA resources include a design guide for exterior panels, an exterior panel paint guide, design guide for structural parts and materials comparison models. These resources can be obtained from the ACA/ACMA website at www.acmanet.org.

Figure 1. Automotive Composites Alliance – A resource for designing with thermoset composites.

In Europe, the European Alliance for SMC/BMC [4] also publishes a series of design guides available to the design and (paint) processing engineer. Their catalogue of resources includes:

- SMC/BMC: Design (Guide) for Success
- SMC/BMC for Electrical Applications
- SMC Typical Properties Reference
- Interactive CD-ROM

Documents from the European Alliance for SMC/BMC can be downloaded from their website at www.smc-alliance.com .

Figure 2. European Alliance for SMC/BMC has a series of design resources: “Design for Success.”

Design and Simulation Software for Thermoset Composites

There are several software packages for finite element analysis (FEA) available on the market today. For static analyses, most FEA tools are adequate if modulus is considered linear over the strain range and geometry does not change sufficiently enough to affect the overall stiffness of the part. Many packages can also perform dynamic analyses. Some of the more popular products include Vanderplaats Research & Development's GENESIS®, MSC Software's NASTRAN®, Dassault Systèmes' SIMULIA® (a.k.a. ABAQUS®/CATIA®), and ANSYS' LS-DYNA™. If not included in the basic software, add-on packages are also available to do more complicated or specialized evaluations. For example, AlphaSTAR Corporation's GENOA®® software adds the capability to perform progressive failure analysis (PFA) and is compatible with most basic FEA packages.

The methods for compounding and molding composite materials, especially SMC and BMC, can introduce significant variability to the finished part. Results from Davis, Gramann and Rios showed that physical property differences can vary up to 100% when fiber orientation is taken into account [5]. So, in addition to performing a "basic" finite element analysis, the designer must also account for variation in properties due to processing. Flow, cure behavior, fiber type, fiber distribution, alignment and geometry of the part can all be significant factors in actual performance.

The Madison Group's Cadpress® is one software package able to simulate SMC and BMC behavior in the mold. Building on research conducted at the University of Illinois and industrial research labs in the mid-1980's, and later refined by work completed at the University of Wisconsin-Madison, fiber orientation, shrinkage and warpage can be computed with a high degree of accuracy [6]. M-Base Engineering + Software Gmbh also provides simulation for compression molding with its EXPRESS™ and FIBERSCAN™ analysis packages.

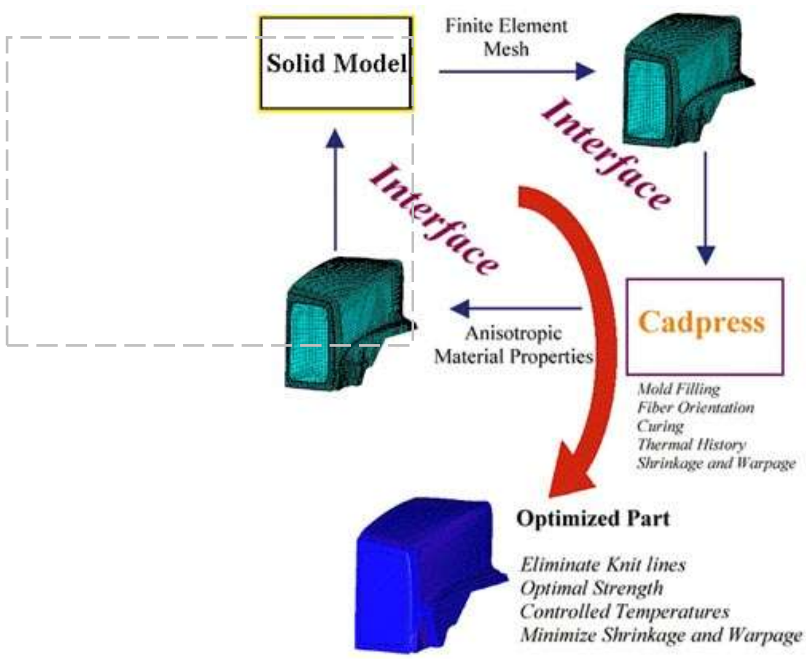

Figure 3. Cadpress® (SMC) finite element compression molding simulation program from The Madison Group.

Thermoset Composites Material Property Data

Although an adequate number of tools now exist to analyze composite materials, a model is only as good as the data associated with the material in question. Property databases for thermoset composites, especially SMC and BMC, are relatively sparse compared to those available for steel. However, they do exist. Material properties for model construction can be obtained from a few third party databases and are easily integrated into most FEA programs. These include Automation Creations' MatWeb® portal, IDAC Ltd.'s Non-Linear Materials Library, and NASA's Materials and Processes Technical Information System (MAPTIS) [7]. Information most lacking from these sources, however, is high strain rate data (for crash behavior analysis) and fatigue data (alternating loads) for thermoset composites. Work continues toward making these material properties more widely available.

Conclusion

The inherent complexity of composites has slowed the pace of developing more accurate engineering models. This is especially true for those materials whose processes have random fiber placement such as SMC and BMC. A designer must consider the effects of mold filling, fiber orientation, and other factors in order to optimize a design. This increased level of difficulty has probably discouraged many automotive designers from using thermoset composites more widely.

Nevertheless, resources and tools for designing with composites are becoming more accessible, more accurate and easier to use. Qualitative guides provide a good starting point for designing with composites. From there, however, digital design and finite element analyses are the best tools to achieve a truly optimized part. Suite software and add-on packages allow engineers to perform advanced analyses that simulate molding and dynamic behavior. A more complete library of properties is all that remains to give engineers the necessary information and greater confidence to design with thermoset composites.

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