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The Composite Materials Manufacturing HUB – Crowd Sourcing as the Norm

by

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Abstract

The Composites Manufacturing HUB puts composites manufacturing simulations in the hands of those who need them to invent new and innovative ways to capture the extraordinary benefits of these high performance products at an acceptable manufactured cost. The HUB provides the user simple browser access to powerful tools that simulate the actual steps and outcome conditions of a complex manufacturing process without the need to download and maintain software in the conventional manner. Learning use of the manufacturing simulation tools will also be accomplished on the HUB in order to allow for continuous learning and growth of the human talent required in composites manufacturing.

Need for manufacturing simulation

Simulation in the design of composite structure has developed during the past four decades to a level of sophistication that allows for the successful design of complex integrated structural geometries consisting of multi-axial composite laminates of curvilinear geometry, sandwich construction, adhesive and mechanical joints, as well as, monocot constructions that possess significantly less sub-assemblies over their metallic counterparts. The Boeing 787 Dreamliner is one example of the success that this simulation capability has achieved to date (1). Here the forward fuselage shown in Figure 1 (40-ft. in length and 20-ft. in diameter) is designed and constructed as a single assembly. Simulation of the complex geometry and performance characteristics of this composite structure were enabled through geometric modeling, multi-axial laminate analysis of the material architecture and structural analysis of the forward fuselage structure. Sophisticated computer simulation codes now offer simulation tool sets that address these design issues.

Simulation of the manufacturing of composite structure is not at the same level of development as that of design simulation. VISTAGY Inc. (Waltham, Mass.) recently announced the results of its composites engineering benchmarking survey entitled, "How do your Composite Design Processes Compare to Industry Best Practices?"(2) The results of the study revealed that only 56 percent of the composite design companies surveyed considered themselves knowledgeable in composites manufacturing practices and were able to apply that knowledge during design. This suggests that 44 percent of companies need to enhance their knowledge of the manufacturing process if they are to improve their competitiveness.

The process for developing new manufacturing simulation tools remains in its infancy. Unlike design simulation software, the manufacturing of polymer composite materials and structures involves multi-physics phenomena such as the curing reactions of thermoset polymers, melting and solidification of thermoplastic polymers, flow and impregnation of viscous polymers in fibrous preforms and tows, consolidation of fiber preforms, conduction and convective heat transfer, geometric conformation of fiber preforms to curvilinear surfaces, residual deformations due to anisotropy in thermal expansion and tooling-composite thermal interactions. These phenomena span the disciplines of polymer science, rheology, reaction kinetics, fluid mechanics of non-Newtonian liquids, heat and mass transfer, mathematical topology, anisotropic thermoelasticity and viscoelasticity. While multi-physics analysis tools have recently been introduced, their use in composites manufacturing simulation is still quite early. There are commercial tools offer a broad range of physical modeling capabilities to model flow, turbulence, heat transfer, and reactions for industrial applications.

There is a strong economic driving force from the automotive industry to accelerate the development of manufacturing design tools and to discover lower cost manufacturing techniques. More recently, specialized simulation tools have been developed to address specific aspects of composites manufacturing. There is a commercial suite of software tools that supports multi-axial laminate definition and generation of flat patterns for sharing design data with the manufacturing floor. This tool creates ply geometry by defining transitions with sequence, drop-off and stagger profiles that automatically populate the CAD model. It can determine variable offset surfaces and solids, including mock-up surfaces for interference checking, mating surfaces that model where two parts join together and tooling surfaces for manufacturing. The tool provides manufacturing details such as splices, darts and tape courses and can develop data such as flat patterns and data to drive automated cutting machines, laser projection systems, fiber placement machines and tape laying machines. Another type of simulation tool, uses finite element (FE) software to simulate large deformations of highly anisotropic materials in the sheet forming process. There is also a commercial tool that simulates the curing and thermal deformations of thermoset polymer composites. Its foundation is a coupled thermochemical-stress-flow model with a dynamic autoclave controller simulation. It is, in essence, a virtual autoclave, equipped with capabilities enabling one to consider the following process parameters: heat transfer/autoclave characteristics, resin cure kinetics, multidirectional laminates/fabrics, honeycomb panels, thermal expansion/resin cure shrinkage and tool-part interaction.

These examples illustrate the growing competencies in composites manufacturing simulation, but to provide the most value for the composites industry it is essential that these simulation tools be linked in a manner that provides for the modeling of the complete manufacturing process. Only then can the true economic benefits of composites simulation be realized. Further, access to the current suite of simulation tools is limited to individuals who have access to large scale computing and to organizations who have purchased expensive licenses for the simulation tools. Entrepreneurs who will significantly accelerate the innovation and development of this powerful set of tools, as well as, the composites manufacturing field, are at a severe disadvantage, because the overhead of just one set of commercially available simulation tools is substantial.

Composite Materials Manufacturing HUB characteristics and functionality

The Composites Manufacturing HUB is a cloud-based cooperative platform that hosts composites manufacturing simulation tools that may be accessed with a web browser from the Internet. The National Science Foundation provided the funding to develop the original HUB concept. There are currently 20 types of HUB organizations using the platform and software. The most successful HUB involves the subject of nanoparticles. To date that HUB boasts 10,000 users worldwide. It has over 350,000 simulations with over 210 engineering tools to simulate important nano phenomena important in nanoelectronics, materials science, thermal science, physics and chemistry. Over 2,500 content items such as tutorials seminars and full classes drive the overall community to over 175,000 users annually. The user community connects students at all levels, research professionals, faculty and industrial users. Tools range from molecular modeling and simulation to photonics.

The Composites Manufacturing HUB has adopted the same platform functionality, which allows users to access tools on a server via web browser. Tools hosted on the Composites Manufacturing HUB can range from simple tools that require only small amounts to computational cycles and those that require the power super computing systems. The HUB provides access to the appropriate level of computing power for each tool and user problem. Further, the platform hosts learning tools that teach the underlying principles upon which the tool is based and demonstrate the correct use and limitations of the tool. Examples of tools include simple engineering mechanics formulations and models of heat and mass transfer essential to simulate composites manufacturing processes. Molecular modeling simulation and uncertainty quantification will inform all the manufacturing process simulations to provide guidance from first principles and to account for process variability.

The HUB will also provide a forum for evaluation of tool performance by the user community though hosted discussions and rating systems. The HUB community can post “Wish lists” on the HUB for discussion. Tool developers are rewarded for both tool use levels and the development of new tools through funding developed by the HUB. Tools developed and placed on the HUB are subjected to a financial analysis to determine their worth to the HUB and the developer is rewarded accordingly.

Specific composites manufacturing processes is the focus of the Composites Manufacturing HUB. While the choice of manufacturing processes is initially limited by the tools currently available, the number of process simulations will be expanded by new tool development during the program. Indeed, it is likely that the available tools on the HUB will be continuously changing as tools are invented, developed and matured. Over time mature tools will likely be migrated to commercial support enterprises. As such, the HUB embraces technology readiness levels (TRL) of TRL 2 through TRL 6 and fosters rapid deployment of manufacturing processes poised for commercialization.

The HUB simultaneously embraces technology readiness levels of TRL 2 through TRL 6. At the TRL 6 level, existing simulation software is provided to the user community with the goals of education the user community in tool use and establishing gaps in functionality required for complex composites manufacturing process simulations. The TRL 2 level work is the research necessary to address the scientific foundation of the simulation tools identified to fill the missing gaps. In this way, the Composites Manufacturing HUB provides a "food chain" for development of the comprehensive portfolio of manufacturing simulation tools needed to meet the expanding need for composites manufacturing simulation.

This technical approach, of hosting existing simulation tools, exposing them to a relevant user community, and supporting the development of new/better tools, is based on solid experience in both the hosting and development elements of the project. Approximately half the effort supports the Composites Manufacturing HUB infrastructure to provide access of tools to the user community, while support for research and development of new simulation tools is the second major goal of the CM HUB.

Description of Hub operating principles

The Composites Manufacturing Hub provides all the functionality of the nanoHub.org and more. The Hub user community promotes broad-based innovation across all sectors of composites manufacturing. An organization or person, who develops an idea for manufacturing of composite structure, accesses the simulation tools and data to evaluate the concepts through a virtual design and manufacturing process. The economics of the manufactured products can be evaluated and numerous scenarios studied to achieve near optimum conditions prior to development of the actual prototype system. This avoids the expensive trial and error approach now so prevalent in much of manufacturing, and it would allow a much larger design space to be explored by the user.

The Hub is a clearinghouse for tools developed for composites design and manufacturing. The simulation tools are hosted on the Hub with all its allied support mechanisms. In the development stage, corporate sponsors jointly support the Hub in order to have a view of all the tools as they develop in one place and can assess their relative strengths. A tool builder places the tool on the Hub, supports its use and retains ownership. The ultimate goal is to host all the tools (in the world) currently available on the HUB. Commercial simulation organizations use the HUB to expose their products to the user community and to provide education in tool use. Hub tool evaluations allow users to judge the relative strengths and weaknesses of the tools in their applications. Access to tools is governed by a use policy wherein the small user is subsidized. The users would provide ongoing support of the Hub in use fees. Much of the nanoHub sociology is adopted for the Composites Manufacturing Hub, so that there can be a composites skunk works in every manufacturing organization!

Manufacturing Design Examples

Two examples will serve to illustrate the power of these composites manufacturing simulation tools. In the first case, it is desired to determine the final shape of a component fabricated of carbon fiber/epoxy unidirectional prepreg tape. In this case a simple angle structural element is desired, but the well known "shrinkage deformation" phenomenon resulting from thermal and chemical shrinkage of the epoxy during cure can produce a final geometry after cure significantly different from the designed shape. The first step in the process is to design the geometry of the structural element including the laminate lay-up that is optimum to meet the geometric constraints of the desired element. Use of software modeling provides the necessary functionality. Next a finite-element analysis (FEA) of the structural element is carried out to ensure that stiffness and strength performance requirements are satisfied. This process involves creation of a FEA model using a software program. When the geometry of the structural element involves curvilinear surfaces, the conformation of the unidirectional prepreg tape to the tool surface is determined form a simulation tool. In other cases such as textile preforms and prepreg, the transformation of the planar sheet material to the curvilinear geometry requires that an analysis of the sheet forming process be carried out with simulation tools. In order to determine the contribution chemical and thermal shrinkage on final shape and to specify the appropriate cure cycle for the specific polymer system, an analysis of the curing kinetics and resulting shrinkage is required. The output of this analysis can then be fed into the original FEA tool in order to determine the final part geometry after cure. By iterating the process, it is possible to choose an initial tool geometry that will yield the desired structural part geometry after the thermal and chemical shrinkage have occurred. This process is summarized in Figure 2 below.

The second example is for the molding of discontinuous fiber composite materials where the flow of the polymer and fiber during molding determine the insitu fiber orientation geometry and thereby the performance characteristics of the molded part. The complex interaction between mold geometry and flow pattern within the mold act on the fiber ensemble as it enters the injection mold or as the compression mold closes around the preform. Flow of the system is influenced by the local temperature and viscosity of the system, as well as, the character and extent of the deformation. For example, shearing deformation very near the mold surfaces tends to align fibers in the flow direction, as does converging flows. It is not uncommon for fibers to be highly aligned near mold surfaces while interior regions exhibit more nearly random states of orientation. The Simulation of molding with discontinuous fiber/polymers is illustrated in Figure 3.

The first step in this analysis is to determine the temperature of the mold and composite during the molding process. This is accomplished with a thermal analysis of the tool in order to establish the conditions for the flow analysis carried out in the second step. In the third step the kinematics of fiber orientation is modeled so that the final state of fiber orientation can be determined at each material point within the molded part. Simulation tools provide the FEA computational capability to carry out each of the first three analyses. Given that the effective thermo-mechanical properties of the composite material are uniquely determined by the volume fractions of its constituents and the local fiber orientation distribution, a micromechanical analysis is necessary to predict the local properties of the material. Here it should be noted that the concept of a material with uniform material properties throughout the part is never achieved in molded products. Rather, each molded part consists of a family of material microstructures and resulting thermo-mechanical properties. These properties must then be reflected in the solid FEA model constructed in the next step. Micromechanical analyses of the material in the region of each element provide the input element properties for the FEA simulation. The solid FEA analyses provides the deformed geometry of the molded part that is often quite different from the mold shape due to the anisotropy of the coefficients of thermal expansion of the composite. The same FEA analysis is then utilized to predict the performance of the molded part to the service-loading environment for which it was designed.

These two examples show how manufacturing simulation is essential for composite materials and structures. With a robust array of simulation tools, the heuristic character of manufacturing of composites can be transformed into and engineering and science-based process where significant economy can be realized.

Summary

In summary, the Composites Manufacturing HUB offers the potential to significantly accelerate the development and lower the cost of composites manufacturing by making simulation tools available through the browser of a personal computer. Further, it provides a platform for the integration of simulation tools so that the complete manufacturing process can be modeled to yield trade study functionality that should significantly reduce the cost of developing manufacturing methods to meet specific needs. In addition, the hosting of simulation tools on the HUB provides opportunities to assess performance and become familiar with commercial and emerging tools as they evolve. In this manner, the HUB is a vehicle to determine unmet simulation tool needs and to become a platform for evaluation of new tools as they are developed. Finally, the HUB assists tool developers in the integration and connection of tools to provide broader functionality and applications.

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Figure 1 Boeing 787 Dreamliner forward fuselage manufactured by Spirit Aerosystems (3)

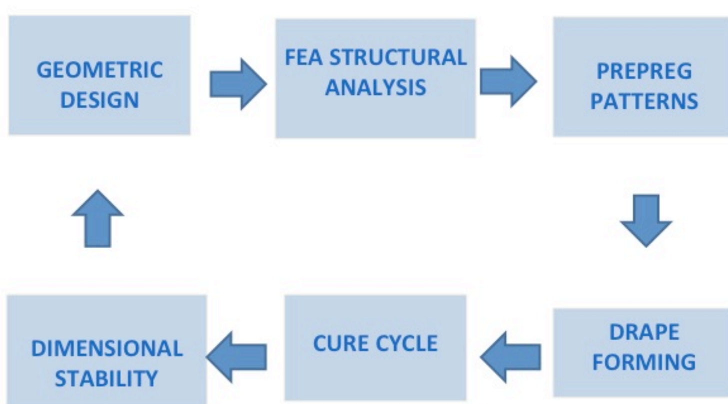

Figure 2 Carbon fiber prepreg manufacturing simulation

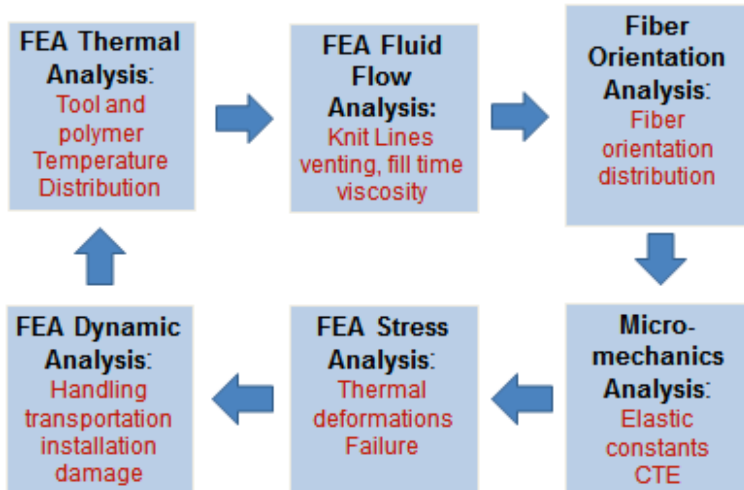

Figure 3 Composites molding simulation