SIMULATING THE ADDITIVE MANUFACTURING OF COMPOSITES

Dr. Byron Pipes is the executive director of the Composites Manufacturing and Simulation Center at Purdue University, as well as John L. Bray Distinguished Professor of engineering. Dr. Pipes has been working with composite materials since 1969, and humorously refers to himself as the "Godfather" of the field. Today, he and his team use both CATIA and SIMULIA's Abaqus FEA, among other solutions from Dassault Systèmes, to simulate the process of manufacturing composite materials employing additive manufacturing (AM, aka 3D printing).

How did you become involved with composites?

It was an easy decision for me. After receiving my Master's at Princeton I was offered two different positions at General Dynamics. One of the jobs I was offered was to join a group working with composites and I chose that position for one reason: I saw the most interesting, intellectually exciting group of people I had ever seen working together in a new subject. Prior to my accepting the position, they had been searching for a way to make an airplane from carbon fiber. Everything from the design, engineering, materials development and so on was happening right there in Fort Worth, Texas, and I was eager to join in because I saw such a creative group of people doing such interesting things.

In a world revolving around mathematics and computational numbers, how were you drawn to simulation?

My simulation background dates back to my career in civil engineering where I was a structural engineer. Finite element methods were developed out of the civil engineering profession. I had the background for it, I saw it coming, and I saw what could be done. That being said, the simulation tools available at the time were nowhere near as powerful as they are today. When we looked at creating a complete finite element model of the F-111 airplane, there were roughly 5000 degrees of freedom for the entire model. Today, with cloud computing access to high performance computing, it is not uncommon

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to have millions of degrees of freedom in models. That gives you some sense of the computational power of the day and how much more powerful the software has become. Today, not only are simulation tools more sophisticated, but so is our ability as engineers to use them in different ways. For example, much of past manufacturing has been empirically developed. Now we have the power to build the virtual manufacturing system that allows rapid optimization of these complex processes.

How does your work with composite materials research, education, and development translate into requirements for Additive Manufacturing?

3D printing is a big subject, so I've really focused all of my attention towards a subset of the industry that relates to the printing of carbon fiber-reinforced polymers. Much of AM today is either printing metals or polymers, and not reinforced materials. As soon as you put fiber inside a polymer, you have created a composite. When printing this material, it has all the aspects of a composite material, namely the high degree of anisotropy—materials that have properties that depend on their 'direction.' For example, the direction parallel to the grain of a plank of wood is stronger than the direction perpendicular to the grain. In the case of fiber composites, it is the fiber direction that defines the maximum strength.

In these systems, fiber orientation produces its anisotropy in the printed material. This means we have another degree of freedom to consider—and that design isn't solely defined by the geometry of the product you're making and the material you're making it from. Instead, you must control the direction of the material and its strength properties and point them in the direction where the most strength is required.

The 787 aircraft was designed with unidirectional fibers made up in thin layers. We made the airplane by layering fiber layers that are about one tenth of a millimeter thick on top of one another. This gives you the ability to design for the complex stresses that exist in the material itself.

Note that biological materials that we are all made of are themselves highly anisotropic. Nature's done this for a long time. We're just now being able to copy nature in real structural materials made of carbon fiber.

How does Abaqus enable your AM research and adoption?

Abaqus is the backbone upon which we're building the foundation for the simulation of AM with composites. It has wonderful functionality and works extremely well with anisotropic materials. We've even taken Abaqus beyond structural simulation and used it to simulate flow processes as well. When 3D printing, the composite material goes from liquid to solid as it melts and it cools and we have anisotropy in the flow characteristics of the material as well. Essentially, if you put long fibers in the polymer it will not flow very well in the direction of the fibers.

In addition to Abaqus, what other simulation tools do you and your students use?

We are using the **3D**EXPERIENCE platform, although it is relatively new to us. As we become more familiar with it I am sure we will make more use of it, but for now our main tools are CATIA and Abaqus. We are educating our students on utilizing this software and are working to develop something we call the 'composites design studio.' We will be able to hire students for 20 hours a week to sit in the studio and use simulation to solve industry problems within the Institute for Advanced Composites Manufacturing Innovation (IACMI).

The beauty of using CATIA and Abaqus is that they talk to one another. CATIA delivers geometric information and Abaqus takes that information and carries out a physics-based simulation. With such complex geometries that we deal with on a daily basis, we need a software like CATIA that is able to reflect the anisotropic properties composites and how they are deposited. From that deposition process we can determine the orientation state of the fibers and the resulting composite physical properties, those properties are then mapped into Abaqus where physics-based analyses are carried out.

Also, IACMI needs a data management and collaboration system to manage its business. For this, the organization will leverage ENOVIA capabilities within the **3D**EXPERIENCE platform. You can imagine how complex this management problem is: IACMI has five Technology Areas that are all located in different states with a ton of information flow that must be managed, along with deadlines and other schedules. ENOVIA will also be installed on the cdmHUB at Purdue so that all of our related information and models will be accessible at IACMI headquarters in Tennessee and we will be able to access the information and data being shared by them. The solutions from Dassault Systèmes will provide not only the technology for design and simulation, but efficient and effective communication and collaboration as well.

Where do you see the additive manufacturing of these composite-based materials headed?

I've recently had the chance to talk to materials suppliers in this field, all of which are sponsors of the IACMI operation. Together we came to the conclusion that the 3D printing of fiber-reinforced polymers will exceed the volume of injection molding of those same materials in a short time. Imagine what that would mean for the future of simulation software. When you design and build a new product, you must have simulation tools with the ability to model the process by which the manufacturing occurs. The 3D printing industry is going to continue to grow and I'm convinced that the roles Dassault Systèmes CATIA and SIMULIA play in supporting its growth will be equally exponential, as they continue to provide the simulation tools of choice for 3D printing of carbon-fiber materials.

For More Information

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