FOCUS

Simulating Reality: Going Beyond Counting Pores and Cracks in Additive-Manufactured Parts

by Kerim Genc

There are several options available for fabricating industrial parts, including additive manufacturing (AM) and subtractive manufacturing (SM). During AM, layers of material are successfully generated in order to build a physical object. This process is often referred to as 3D printing. By contrast, SM removes material sections through machining and cutting processes; for example, through computer numerical control (CNC) machining.

AM processes are typically used in product design and prototyping, where smaller, or more intricate, components are needed. These components are typically made using materials such as plastic, polymers, ceramic, or metal, and, depending on the application, manufacturing is scalable to different industrial requirements. By contrast, SM is a more manual process that is better suited to larger metal parts.

The range of AM technologies is classified into several categories, including binder jetting, material jetting, direct energy deposition, sheet laminations, material extrusion, powder bed fusion, and vat photo-polymerization. Each category includes several different processes; for example, an incomplete list includes stereolithography (SLA) and selective laser sintering (SLS) for polymers and composites, and selective laser melting (SLM), binder jet (BJAM), and electron beam powder bed (EBM) for metals. A detailed explanation of these processes is beyond the scope of this article; however, interested readers can refer to a paper published in Materials Evaluation for an overview of the various techniques used in AM (Hassan and Kirka 2018).

AM for Orthopedics

AM is ideally suited to making orthopedic devices because it allows for the freedom to create highly complex parts, eliminates the need for dedicated tooling, and allows for unparalleled design flexibility for patient-specific needs. Despite these advantages, however, there can be problems with accuracy, quality, strength,
and long-term reliability. To address these issues, several post-manufacturing quality assurance techniques incorporating nondestructive testing (NDT) have been developed in the industry (such as radiographic testing, ultrasonic testing, and liquid penetrant testing) with varying levels of success depending on their context of use and which AM technique was used.

Manufacturers typically compare the geometric differences (cracks, pores, and the like) between the computer-aided design (CAD) and reality (the as-manufactured part) by using either computed tomography (CT) or optical surface scanning techniques. However, this process may not tell the whole story since geometric deviations from design do not necessarily indicate how the part will perform once deployed in the real world. The standard approach to understanding performance under real-world loading conditions has been through either benchtop testing, which is expensive and limited in scope, or CAD-based finite element (FE) simulation, which uses a numerical representation of the structure to solve physics-based problems. Although FE simulations can widen the scope and reduce cost, they are typically based on an idealized geometry that does not always represent the as-manufactured reality. Using CT scan-based modeling techniques that link 3D imaging and FE simulation allows manufacturers to nondestructively compare the performance of as-designed and as-built AM parts, telling a more complete story of the effectiveness of the build and quality of the part.

**Spinal Truss Example**

In the area of orthopedic devices, we have recently seen this CT image-based modeling technique work well for a project on an AM spinal truss device manufactured using electron beam melting and designed to stimulate bone-implant integration and joint stability. A streamlined proof-of-concept workflow was set up to link CT, AM, and FE simulations, beginning with a scanned 3D-printed implant. Image processing software was used to work on the image data, carrying out virtual deviation analysis between a CAD design and the scanned part, and export high-quality models into simulation software to compare the performance of the original design and actual part.

Results showed good agreement between the two sets of data, and performed comparably for simulating plastic strain and displacement, with differences in yielding, or permanent deformation, still being safe for patients. These results were expected since the current workflow is an initial proof of concept on a device that was already cleared by the FDA and is in

![Figure 1](image-url). Example workflow for comparison: (a) as-designed (CAD) part (left) and CAD-based simulation (right); and (b) as-built AM part (left) and image-based simulation (right). Note: Simulated loads were well above typical physiological loading conditions, and the displayed preliminary results are shown as a color map of stresses.
full production. The goal of this project was to establish the workflow, validate it with physical testing (currently being performed), and then apply it earlier in the design workflow for future devices.

The comparison of the as-designed workflow to the as-built workflow is shown in Figure 1. Figure 1a is a model of the spinal truss created in a CAD program and then sent to an FE simulation program to simulate as-designed stress under a compressive load. Figure 1b is an AM part (as-built) that is then CT-scanned, imported into a 3D image processing software, and then exported to an FE simulation program to calculate the as-built stress under the same load.

A particularly useful step in this project involved using software to overlay the CAD and as-built models of the part, as seen in Figure 2. From this model, we then generated a heat map (Figure 3), showing deviations between the idealized design and the actual part that was CT-scanned, which allowed for an analysis of the changes that occurred during the manufacturing process.

We found that this approach was beneficial as a proof of concept for the device manufacturer, as it generated quantitative data for going back and adjusting the AM process to minimize the impact of functional differences in a final product. Comparing as-built and as-designed parts through virtual simulation-based NDT is scalable to greater levels of detail and is also applicable to nonmedical industrial parts and any work involving AM parts. We are seeing positive ongoing work in this area and believe it should help make AM a more common part of future manufacturing workflows.

ACKNOWLEDGMENTS

The author thanks A. Kiapour (4Web Medical), H. Villarraga-Gómez (ZEISS), Y. Wang (Thornton Tomasetti), P. Tomsett (Synopsys), J. James (Synopsys), and I. Weber (Synopsys) for contributing to this project.

AUTHOR

Kerim Genc, Ph.D.: Simpleware Product Group, Synopsys Inc., Mountain View, CA; kerim.genc@synopsys.com

REFERENCES


