

Inspection of Computed Tomography (CT) Data and Finite Element (FE) Simulation of Additive Manufactured (AM) Components

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Abstract

One of the challenges of working with Additive Manufactured (AM) metal parts involves checking accuracy and reliability before production. Techniques used Computed Tomography (CT) scans, 3D image processing, and Finite Element (FE) simulation help detect problems prior to costly faults. A workflow has been developed by Synopsys, ANSYS, North Star Imaging, and the University of Pittsburgh to streamline this often-complex process, with applications to analyzing metal AM-produced lightweight brackets and a component from Moog, Inc. Software like Synopsys Simpleware™ is used to generate robust models from 3D scans of AM parts to compare original CAD models with ‘as-built’ geometries, and to export a FE mesh for simulation in ANSYS. This method enables identification of design deviations early in the design process, and how their impact might be tackled prior to production. For the Moog application, unexpected defects were identified for aerospace parts to inform future design iterations.

Keywords: Additive Manufacturing, FE Simulation, Computed Tomography, Image-Based Modeling, Optimization

1. Introduction

Additive manufacturing (AM), otherwise known as 3D printing, has broad applications to designing and manufacturing industrial parts. These parts are particularly useful for prototyping complex designs that are optimized for specific applications, for example lightweighting. The real-world performance of AM parts can be simulated using Finite Element (FE) tools to understand how design changes affect performance. Non-destructive evaluation of AM parts is enabled by 3D scanning, for example with Computed Tomography (CT) machines, to generate virtual models of the part that can be comprehensively inspected to identify defects.

However, linking these technologies and methods can be difficult, due to the lack of a straightforward and compatible workflow. This paper discusses how a workflow developed by Synopsys, North Star Imaging (NSI), ANSYS, and the University of Pittsburgh solves these problems by linking 3D CT scans of an AM part to inspection and simulation, and demonstrates the value of these techniques for AM applications. In addition, the paper looks at how these methods have been applied to an aerospace prototype from Moog, Inc.

2. Methodology

2.1 Optimizing a Bracket Geometry

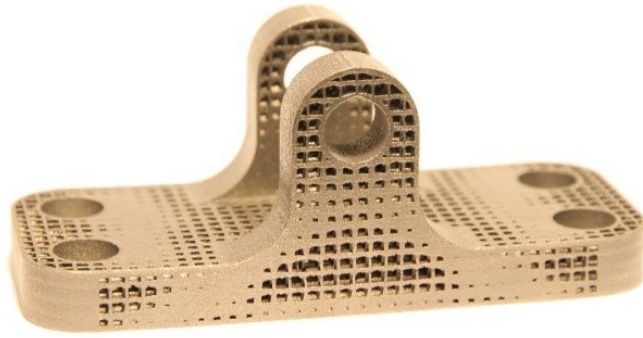


Figure 1. Model of bracket for inspection

The University of Pittsburgh have carried out research into optimizing a typical bracket geometry to include weight-saving lattice structures, part of broader research on AM [1, 2]. Using tools for homogenization and structural optimization in ANSYS (ANSYS Inc., Canonsburg, PA), researchers at Pittsburgh re-designed a part to include these features. From this design, the part was built using a titanium alloy (Ti6Al4V) in an EOS Direct Metal Laser Sintering (DMLS) Additive Manufacturing machine (Model M290). This part was then ready to be virtually evaluated in order to better understand its design features and ‘as-built’ performance against the original CAD model.

2.2 Reconstructing and Inspecting the Part Geometry

The printed brackets were reconstructed by North Star Imaging using a computed tomography (CT) scanner. The North Star Imaging engineers used subpiX software to accurately reconstruct the part and achieve a suitable contrast between different regions while obtaining a clean surface. The size of the part required low magnification, as well as high-power tube settings and pixel binning of the detector to achieve a scan at 30 frames-per-second (FPS). This high-quality scan was completed within two hours, and the projections taken every quarter of a degree, enabling a faithful reproduction of the part.

2.3 3D Image Processing

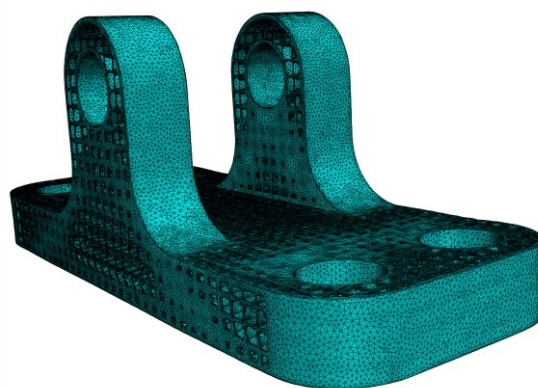


Figure 2. Synopsys Simpleware ScanIP model of the bracket

The CT scan data was imported to Synopsys Simpleware software for 3D image processing and export of models to simulation. Using image data is particularly valuable as the scans capture the ‘as manufactured’ geometry of a part, rather than an idealized CAD model that might not take into account fine details. Simpleware software tools were used to segment the part from the surrounding air-space using thresholding and localized methods. Once prepared,

the image data was exported as a high-quality stereolithography (STL) file and a volumetric FE mesh. Time was saved over alternative meshing methods through the ability to export a watertight mesh from Simpleware software to the simulation solver ANSYS without having to repair errors in the solver.

2.4 Comparison of CAD and Image Data

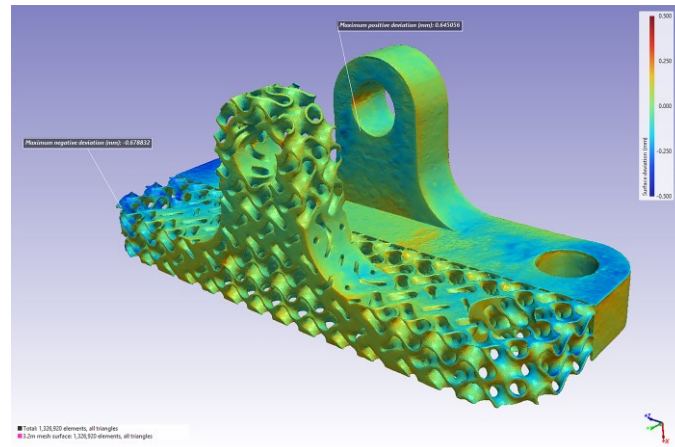


Figure 3. Deviation analysis using Synopsys Simpleware

One of the key goals of this project was to compare the original CAD design of the part with the image-based model taken from the CT data. Taking this approach enables deviation analysis of the original design and the as-manufactured part, taking into account potential errors during the Additive Manufacturing stage. Simpleware software's landmark and automatic registration tools were used to align the CAD and image-based parts. A deviation analysis tool in Simpleware software then enabled differences to be shown between the versions of the bracket. This method showed evidence of a bend in the base of the bracket, likely caused when the part was taken from the AM machine. Broken struts were also found in the lattice, again likely a result of manufacturing error.

Understanding these differences is valuable to understanding how AM parts, particularly when using metals, can include errors that reduce their planned performance. When designing parts for aerospace or automotive applications, non-destructive evaluation of defects is vital for ironing out problems during design iterations. For example, the bracket studied by the University of Pittsburgh was at its earliest design iteration, meaning that the errors found in the part could be factored into the ongoing development of the part.

2.5 Simulating Part Geometry

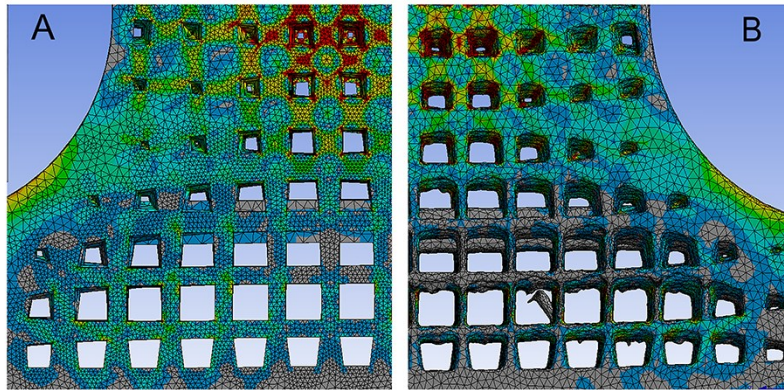


Figure 4. Structural simulation to solve loading problems

As well as the part inspection, the bracket study involved exporting the Simpleware software volume mesh to ANSYS Mechanical software for simulating performance. The ANSYS team used the mesh to test how the virtual part performed under specific conditions, again comparing the original CAD design and the scanned AM part using structural simulation to solve loading problems. Results showed that, although deviation analysis identified defects, the AM component still performed within the limits planned for the bracket.

2.6 Manifold Inspection with Moog, Inc.

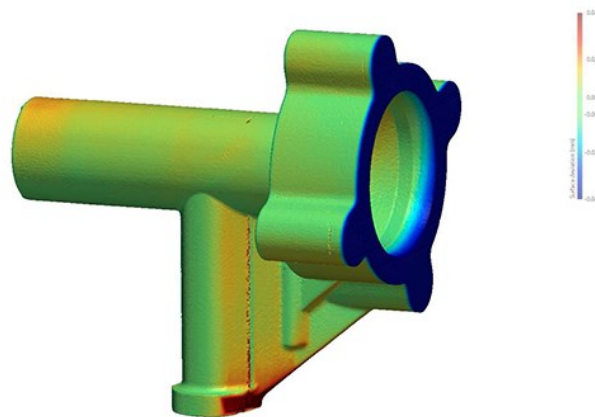


Figure 5. Simulating maximum principal stress using ANSYS Mechanical

The workflow has been applied to a manifold inspection project by Moog, Inc. to solve challenges with manufacturing precision motion control products. Moog's parts are used in automotive, military, and commercial aircraft, and require a high degree of accuracy to avoid undue risk. The typical workflow used by Moog is to create a conceptual design prior to performing simulations in ANSYS Mechanical; results are then used as inputs to printing AM parts on a Renishaw AM250 laser powder bed fusion (LPBF) printer. For this project, Moog were focused on optimizing the design of an impulse pressure manifold to meet material and hydraulic fluid configurations.

The workflow for the University of Pittsburgh part was repeated, with the AM manifold CT scanned by North Star Imaging. Simpleware software was used to segment and process the 3D image data, including visualization of pores, cracks, and residual powder from the AM

process. Comparison of the as-built part and Moog's original CAD design identified geometric deviations, including porosity. An FE mesh was generated from the CAD and 3D CT data and imported to ANSYS Mechanical to simulate maximum principal stress on the manifold.

Results showed that the image-based model of the AM part included a 23.18% increase in maximum principal stress from the original CAD model. The cause of these defects was likely the cracks and pores in the as-built geometry, allowing Moog to better understand where to focus efforts for subsequent design and manufacturing efforts. This non-destructive approach helped Moog to quantify the fitness-for-purpose of their AM parts, reducing potential problems later on in the manufacturing process.

3. Conclusions

The presented workflow provides a method for assessing the usability of AM-produced parts planned for industries such as automotive and aerospace. By quantifying the effect of a defect or geometry deviation at critical locations between CAD designs and as-built parts, researchers can evaluate the effect on structural integrity and fatigue life. Identifying these defects at an early stage of design work means that errors can be removed before costly manufacturing. AM-produced parts can be created with more confidence of their performance under typical uses.

While the workflow shows the challenges of optimizing AM parts to meet initial design expectations, it also demonstrates the benefits of an integrated method for linking the different steps for building and testing models. The test results from the proof-of-concept studies discussed in this paper are promising in terms of generating inspection and simulation results that can be used as valuable inputs to designing future components.

Acknowledgements

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