Standardized Validation Brings Confidence to 3D Printing

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Summary

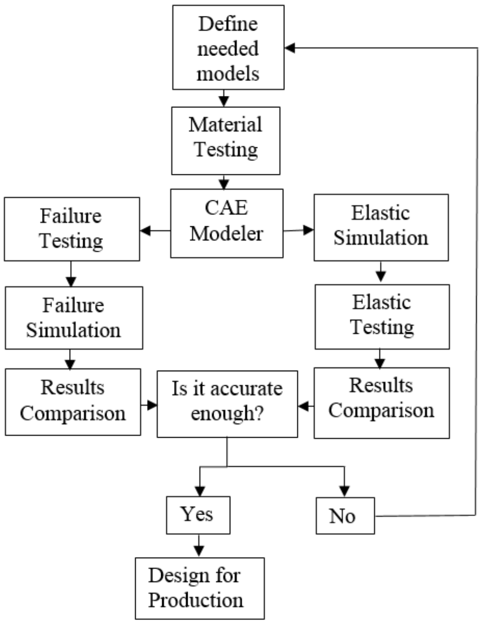
Finite element analysis contains assumptions and uncertainty from a number of sources, which can impact the fidelity of the simulation. This uncertainty is often left untested up to prototyping stages. DatapointLabs' CAETestbench Validation service was developed to add a mid-stage validation step to a designer's workflow, to test these simulations before parts are made, in order to build confidence in an engineer's model beforehand. This validation step is illustrated in a 3D printing application.

Introduction

Direct metal laser sintering (DMLS) and other 3D printing processes have an increased use in the aerospace industry in the last few years. There are many benefits to 3D printing over conventional manufacturing processes: the ability to produce complex geometries that allow weight reduction and part consolidation; the reduction in lead time due to interchangeable tooling between production lines; the comparatively short time from creating the CAD file to producing a production part. These factors make the process commercially viable for one-off and short production runs.

Unlike conventional production processes, the ability to simulate the durability and performance of 3D printed parts is a vital step prior to production, to ensure that parts made using this comparatively expensive process do actually perform as expected. Accurate simulation capability also offers a linear path from CAD to production, where the part can be virtually proven before it is made. All this relies on the ability to accurately simulate the performance of parts manufactured with these processes. Often, properties from a similar material produced by conventional manufacturing processes are used, adding uncertainty to the simulation. Part performance can only be validated once a prototype is made and tested.

In this novel approach, prior to designing the real-life component, a standardized validation step is performed to quantify the accuracy of the simulation using a standardized part. The effects of manufacturing processes, solvers, and materials can all be quantified in this way. With this knowledge, the simulation can now be used during design, and the final part can be printed with a great degree of confidence, thus managing performance risk and production risk (and cost).

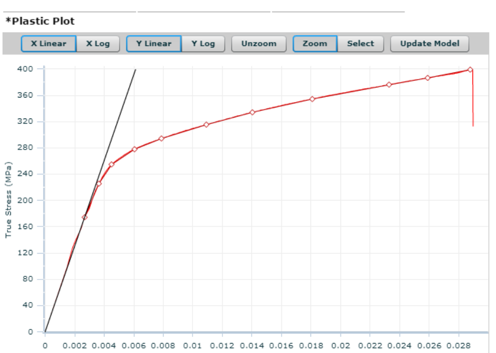


In this paper, we are demonstrating this workflow through the validation of DMLS EOS AlSi10Mg. Validation is comprised of a comparison between measured and simulated elastic strains in bending on the face of a standardized “bike crank” part and progressing onward to the simulation of failure. Simulation models are created using Altair HyperMesh and analyses are performed with Altair OptiStruct and RADIOSS. The material characterization and validation testing were performed by DatapointLabs, LLC.

Selecting Models

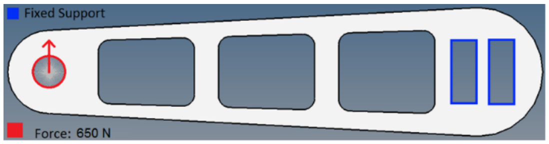
Choosing the deformation modes for the benchmark case is based on the product specifications. These specifications may include actual modes of stress the part sees, the environment in which it is installed, and other significant variables. This particular case would be for bending under normal conditions. Choosing a material model has a similar process behind its selection; for example, in an impact application, a rate dependent material card would need to be developed. In this case, a quasi-static curve is adequate. Material testing is performed to characterize a material under the desired set of conditions and applying the data to an appropriate a material model.

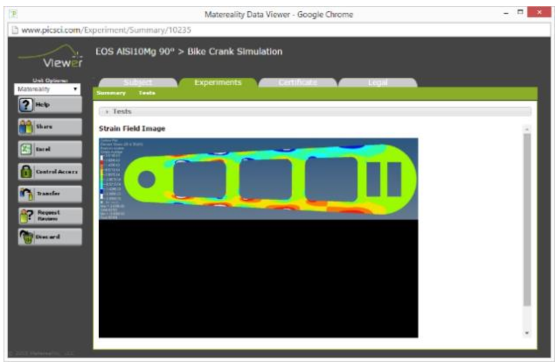
In the case of DMLS Aluminum, it was suspected that the DMLS process of building a part layer by layer would create a product with different directional material properties as compared to a part made by a traditional manufactured process. Concerns also exist about density variation and void formation, all of which could impact simulation accuracy, as well as real world performance. The validation step sought to quantify errors from these uncertainties, as as well as potential limitations in the simulation and material models.



Develop Material Model with Matereality

After tensile testing for stress-strain curves to extract the material properties for both the simple elastic model and the tabulated plasticity model, the curves and values are uploaded to Matereality. Both the material models are created using the CAEModeler. CAEModeler gives the user control to define the stress-strain points used in the table and to define variables, such as modulus and ultimate strength, for the material model. These models are then stored in the user’s Workgroup Material DatabasePro, from where they can be exported to the HyperMesh library using the Matereality-HyperWorks Connectivity.

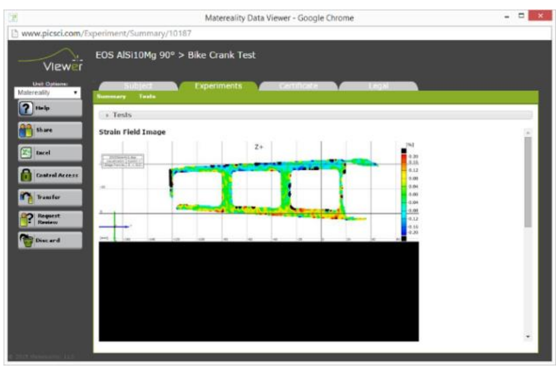




Elastic Simulation with Altair HyperMesh and OptiStruct

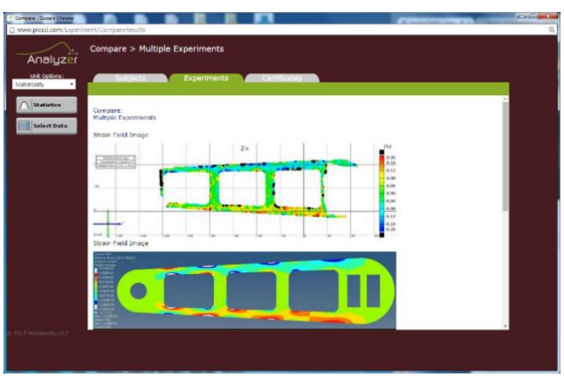
The simulation for elastic strain was created in HyperMesh with a solid map mesh at an average mesh size of 0.5 mm creating solid elements. The boundary conditions include fixing the surfaces of the rectangular mounting holes. The pin hole is loaded at the center with a force of 650N. This case used the MAT1 elastic model with Young's modulus, Poisson's ratio, and density.

The elastic simulation uses a linear analysis for the OptiStruct solver with the small strain option enabled. As a robust solver, OptiStruct is useful for many linear and nonlinear load cases. In our case, the recorded results are simulation images for the normal elastic strains along the length of the crank. These are uploaded to PicSci, an Electronic Lab Notebook that allows easy, cross-platform comparison.



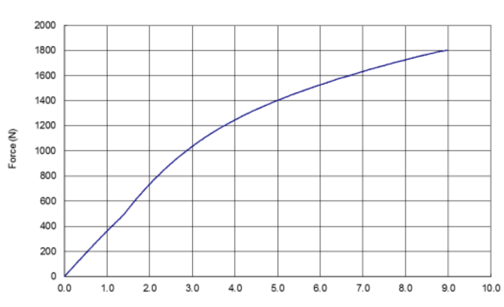
Validation of Simulation by Crank Testing

Running parallel to the simulation is the measurement of the elastic normal strains along the length of the crank. The rectangular holes are mounted in a fixture and the crank is bent using a 650N force on the pin hole through lifting the pin with a Universal Testing Machine. Strains are measured on the face of the crank using Digital Image Correlation, which analyzes the change between stereoscopic images of an applied speckle pattern on the face at each time step during testing.



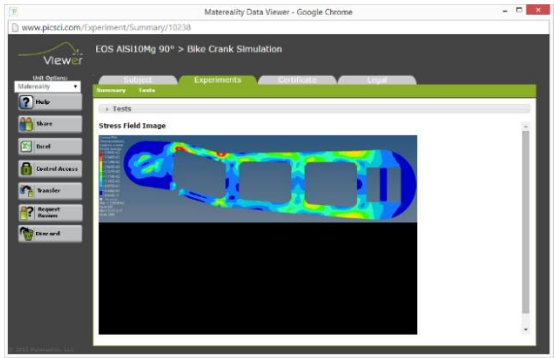
Results Comparison for Elastic Validation

The legends from each strain field are bounded to allow for comparison of equivalent contour colors for the range of strain. Both DIC experiment and simulation show the obvious: generally, compression is on the top and tension on the bottom when the crank is pulled upward. As a quantitative comparison, the contours match between images. A side-by-side comparison is shown in PicSci.



Crank Testing Failure

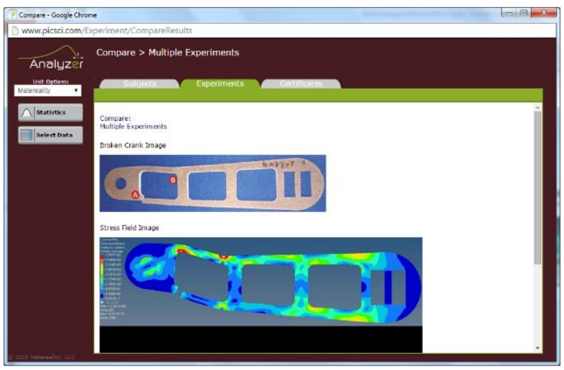
The crank is mounted and bent into complete failure on a Universal Testing Machine, with force v. extension measured. In this case, the crank sustains an 1800N load before brittle failure occurs first in the bottom left hand corner, followed by the upper right corner of that hole. The image of where the crank fractures is uploaded to PicSci for comparison.



Failure Simulation with Altair HyperMesh and RADIOSS

The failure model is also created in HyperMesh, with a refined mesh on the front third by the pin; the refinement is to 0.5 mm, with the rest a coarser mesh. The mounting holes are still fixed, and the load has been increased to 1800N based on the failure testing. The pin is added to the model, requiring a Type 24 contact setting between the pin and the crank. This case uses a tabulated plasticity model to account for the plasticity. Element deletion is enabled based on the failure strains.

The failure simulation uses a nonlinear analysis, the RADIOSS solver. As a robust solver, RADIOSS is useful for many nonlinear load cases handing contact and complex material models. In our case, the simulation images are recorded, demonstrating the where failure occurs. These are uploaded to PicSci.



Results Comparison for Failure Validation

Both a picture of the broken crank and the simulation image are compared. At the applied experimental failure load of 1800N, the RADIOSS simulation also shows failure. The failure occurs at the same locations in simulation and the real-life test. This demonstrates the ability of the solver to correctly predict performance all the way from initial stiffness computations through failure for DMLS parts.

Conclusions

Altair's HyperWorks solvers accurately predict Aluminum DMLS parts when simulated the same way as conventionally made aluminum parts. Specifically, OptiStruct can simulate the elastic strains for AlSi10Mg, while RADIOSS accurately predicts failure.

Beyond this limited condition, this paper explains how validation can give confidence in simulating for the design process. Validating can confirm the ability of the finite element analysis to capture different variables, such as printing anisotropy, FEA solver accuracy, and other material behavior like elasticity, plasticity, and failure. A standardized geometry and load case must be used for quantifying simulation accuracy in these cases.

Acknowledgments

We are grateful to Mr. Kevin Engel and others at Incodema3D for advice on 3D printing and for preparing the test samples; and to Julien Santini and Yuvaraj Rangaraj at Altair.

About

Altair

Altair is focused on the development and broad application of simulation technology to synthesize and optimize designs, processes and decisions for improved business performance. Privately held with more than 2,600 employees, Altair is headquartered in Troy, Michigan, USA and operates more than 45 offices throughout 24 countries. Today, Altair serves more than 5,000 corporate clients across broad industry segments.

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Altair’s HyperWorks is an on-demand software platform that includes statistical, database, visualization and simulation software to help companies make better business decisions. HyperWorks uses a patented licensing technology allowing customers to transparently share licenses globally across a broad suite of applications.

Altair Partner Alliance

Altair’s HyperWorks platform applies a revolutionary subscription-based licensing model in which customers use floating licenses to access a broad suite of Altair-developed, as well as third-party, software applications on demand. The Altair Partner Alliance effectively extends the HyperWorks Platform from more than 20 internally developed solutions to upwards of 60 applications with the addition of new partner applications. Customers can invoke these third-party applications at no incremental cost using their existing HyperWorks licenses. Customers benefit from unmatched flexibility and access, resulting in maximum software utilization, productivity and ROI.

Matereality/DatapointLabs

Matereality and DatapointLabs, USA form a comprehensive resource for strengthening the materials knowledge core of manufacturing enterprises. Matereality’s Software for Materials gives companies the means to build databases to store properties, CAE material files, and material information on any material. The built-in suite of web-based software helps engineers visualize and understand material data, create CAE models and manage materials information. DatapointLabs’ Technical Center for Materials provides accurate material testing, material parameter conversion and model validation services for CAE, allowing companies to populate their databases with high-quality, application-ready data for design and new product development.

PicSci is one of DatapointLabs newer brands. The PicSci platform serves an electronic lab notebook to record, analyze, and share data regardless of topic, using software designed to be better than Microsoft Excel for experimenting.