Distortion Compensation for Additive Manufacturing

ANSYS exaSIM™ is a suite of metal additive manufacturing (AM) simulation tools that provide critical insight into the complex physics-based phenomena associated with laser powder bed fusion. exaSIM generates practical solutions to residual stress, distortion and build failure, enabling users to achieve part tolerances and avoid build failures while minimizing trial and error experimentation and stress relief heat treatments. STL files are automatically distortion-compensated to counteract distortion that occurs during part production.

This case study demonstrates the use of exaSIM's distortion compensation feature to reverse distort a part's STL file based upon the strains predicted in the process. When producing a part using a compensated STL file, the part distorts to the correct shape as the build progresses.

Figure 1. Bike stem geometry (Provided by GRM Consulting and BCIT)

Accurate Path-based Critical Path Timing

When using a laser to melt metal powder, shrinkage strains accumulate as each location melts and cools. These strains create stresses which distort the part from its intended shape. The magnitude of distortion is geometry, process parameter and material dependent. exaSIM simulates the build process using a layer by layer accumulation of strain to predict distortion. This information is used to assess how a particular geometry and support structure will affect a component's final shape.

Bike Stem Example

A topology-optimized bike component (see Figure 1 and http://www.grm-consulting.co.uk/bcit-bike-stem) was provided by GRM Consulting and BCIT. The part was built by Renishaw on an AM250 system using CoCr. Simulation indicated significant distortion of the shock mounts after removal from the substrate. Two parts were built, one with and one without compensation, to test exaSIM's predictions and distortion compensation tool.

Simulation and Build Details

Distortion was predicted using the anisotropic scan pattern strain function available in exaSIM Advanced and Ultimate. The build parameters and simulation assumptions are shown in the table below. The first simulation was performed to determine the appropriate strain scaling factor (SSF) for this machine/material/ process parameter combination. The second simulation was performed using the calibrated strain scaling factor to test the accuracy of the distortion compensation function.

Parameters	First Simulation	Second Simulation
Layer Thickness	30 μm	30 μm
Starting Layer Angle	0 degrees	0 degrees
Layer Rotation Angle	67 degrees	67 degrees
Build Time	~25 hours	~25 hours
Simulation Parameters (Scan Pattern Based Strain)		
Strain Mode	Elastic	Plastic
Strain Scaling Factor	1	2.34
Voxel Size	0.30 mm	0.33 mm
Simulation Time	28h 40m	53h 20m

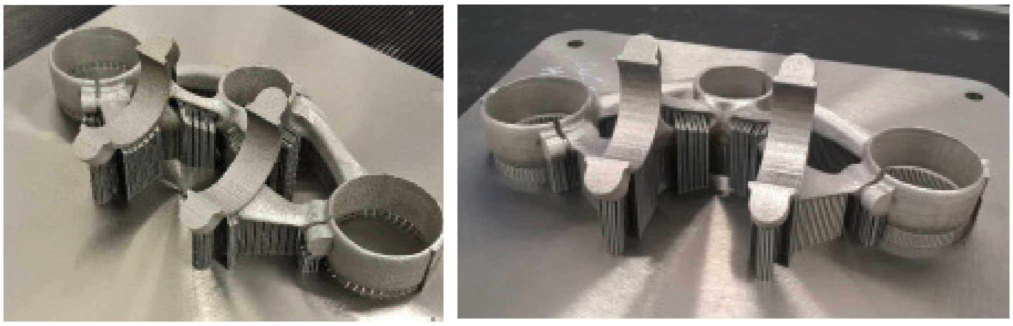

Figure 2. Bike stem builds. (Left) Noncompensated part. (Right) Compensated Part.

Simulation Tuning

To tune SSF, the noncompensated part shown in Figure 2 was compared with the first simulation results shown in Figure 3. The best-fit diameter and center location of all circles were compared between the part and simulation. An SSF of 2.34 was determined by finding the scaling factor which minimized the sum of the absolute difference between the simulation and the as-built part while on the base plate. For the second simulation, in order to predict distortion after removal from the baseplate more accurately, plasticity (J2) was selected. For this geometry, a distortion compensation factor (DCF) of 1 was found to give an after cutoff geometry very close to the target shape. The STL file created by exaSIM for a DCF of 1 was used as the input geometry for the final build.

Results

The after cutoff first simulation results shown in Figure 3 predicted that deformation would be most severe at the shock mounts (outer circles). exaSIM predicted a DCF of 1 would correct this distortion. As can be seen in Figure 4, these predictions were accurate. The distortion-compensated file resulted in a geometry where the shock mounts were built without distortion whereas, when building the part using the original geometry as an input, the shock mounts distorted considerably from the intended geometry. These results illustrate that it is possible to utilize distortion compensation to achieve accurate parts after removal from the substrate, without heat treatment.

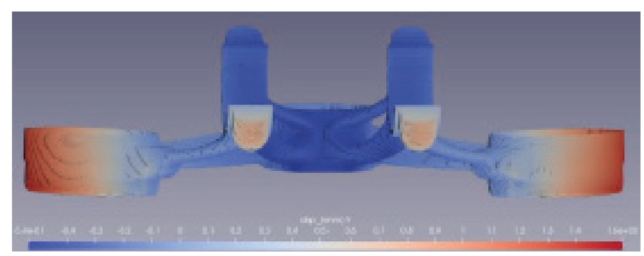

Figure 3. After cutoff displacement simulation results

Conclusion

This case study demonstrates the usefulness of exaSIM's distortion compensation tool. Designers and AM machine operators can achieve accurate parts using laser powder bed fusion additive manufacturing techniques without utilizing expensive heat treatment and stress relief prior to removing a part from the baseplate. By following the process outlined in this case study, exaSIM users can tune their SSF to a specific machine/material/process parameter combination and accurately predict part distortion effects without additional trial and error experiments, saving them time and money.

Figure 4. (Left) Distortion-compensated simulation results in blue superimposed upon the STL file in gray. (Right) Simulated distortion without distortion compensation in blue and red superimposed on the scanned after cutoff results compared to scan data. exaSIM accurately predicted distortion for both cases and provided an STL to correct distortion for this geometry.

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