Additive Calibration Guide

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Release 2021 R1
January 2021

Published in the U.S.A.

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Additive Calibration - Quick Start

In order to achieve the best performance of ANSYS Additive software, we highly recommend that you run a distortion calibration process to best fit your simulation to your specific physical manufacturing scenario. This is because actual distortion values from as-built parts vary across different machine and material combinations, especially considering the differences among various laser powder bed fusion (L-PBF) machine manufacturers and powder material suppliers on the market.

A Quick Start Guide (shown below and also available for download as a PDF) summarizes the process for performing an Assumed Strain simulation type using either Linear Elastic or J2 Plasticity stress mode. Refer to the remainder of this Additive Calibration Guide for further details and for information on calibrations with advanced simulation types.

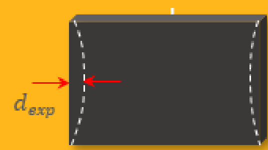
Ansys Additive Distortion Calibration Quick Start Guide

Use this Quick Start Guide to calibrate Ansys Additive software to match your machine/material scenario. The goal is to determine a calibration factor, called a Strain Scaling Factor (SSF), that compensates for the difference between a measured distortion and a simulated distortion. This guide describes the process for performing an Assumed Strain simulation type using either Linear Elastic or J2 Plasticity stress mode.

Step 1

Build & Measure

- Design or choose a calibration part that is easy to build and yields high distortion
- Build the calibration part with the same process parameters you plan to use for your part
- If possible, build the part directly on the baseplate to minimize support structures
- Allow enough room to make measurements while the part is still attached to the baseplate
- After fabrication, measure displacement (d_{exp}) at location of interest



Step 2

Simulate

- Run Assumed Strain simulation type with the same geometry and material
  - Import your calibration geometry
  - Choose your material
  - Set stress mode = Linear Elastic or J2 Plasticity
  - Set Strain Scaling Factor (SSF) = 1 (default)
  - Use default output options
  - Start the simulation
  - Export On-plate stress/displacement
  - Obtain displacement (d_{sim}) at same points and same directional component (X, Y, or Z) as measured

Step 3

Calculate & Compare

- Calculate new SSF: $SSF_{new} = \frac{d_{exp}}{d_{sim}} SSF_o$

  where SSF_o is previous SSF
- Compare difference between d_{sim} and d_{exp} to see if acceptable
  - a) If acceptable, stop here and record SSF_{new} as SSF_{cal}
  - b) If not acceptable, run new simulation as in Step 2 using SSF_{new}. Continue until it converges toward zero or an acceptable level.
- Create custom materials with final SSF_{cal} values in Additive Print (one for $SSF_{cal\ LE}$ and one for $SSF_{cal\ J2}$)

Learn more about Ansys Additive calibration at:
http://storage.ansys.com/doclinks/ansys.html?code=AddCalibration-ALU-M2a

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Additive Calibration - Full Procedure

Important:

For the most up-to-date calibration procedures and parts, including the Calibration Quick Start Guide as a PDF file, be sure to look at our ANSYS Additive Calibration Files page on the internet.

Objective

In real world fabrication scenarios, distortion values within parts vary across different machine and material combinations, especially considering the differences among various laser powder bed fusion (L-PBF) machine manufacturers and powder material suppliers on the market.

The objective of the calibration procedure is to determine the Strain Scaling Factor (SSF) and Anisotropic Strain Coefficients (ASCs) for use in the ANSYS Additive Print software. These calibration factors will greatly improve the prediction accuracy of the simulation software for your specific machine-material combinations, therefore improving the chance of successful builds as well as reducing the cost of trial and error experiments.

Figure 1: SSF required for Assumed Strain simulations in Additive Print

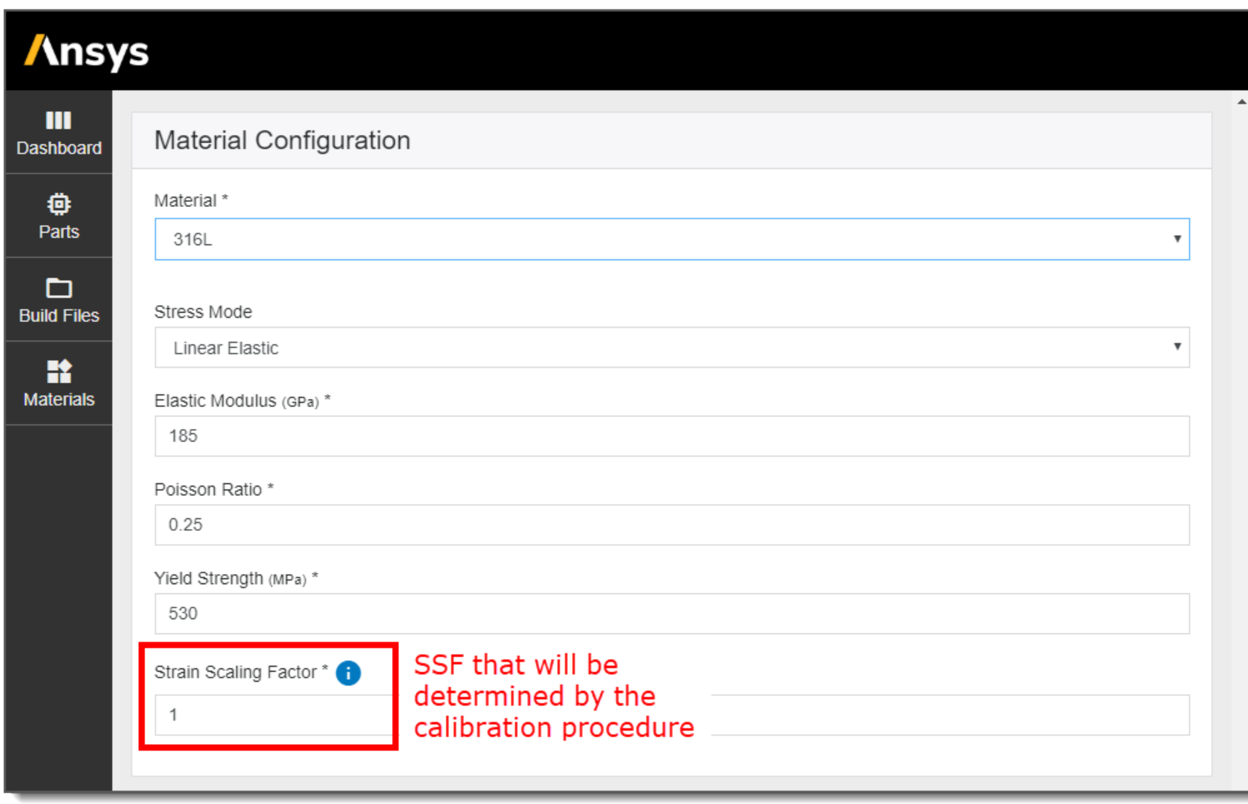
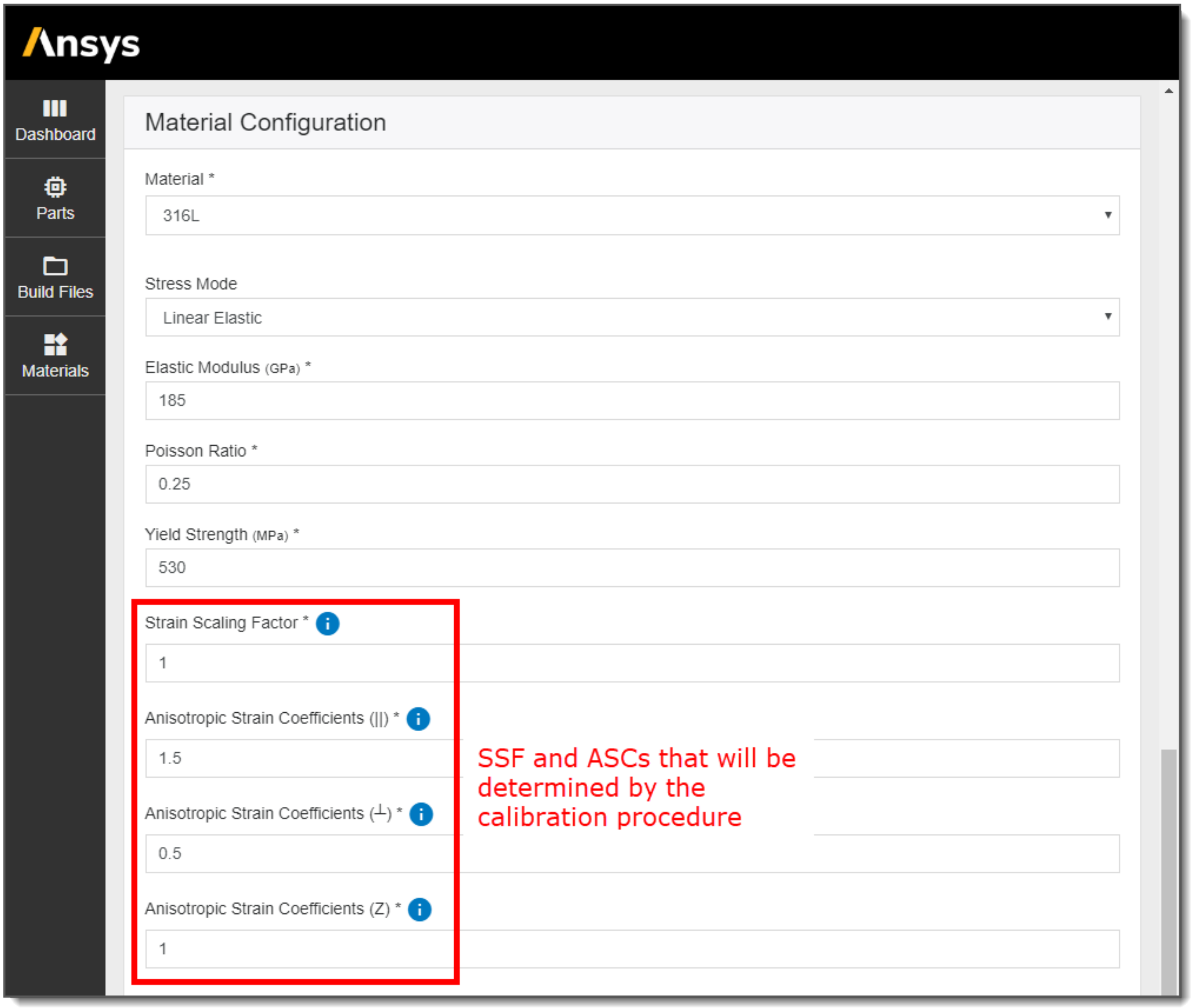


Figure 2: SSF and ASCs required for Scan Pattern/Thermal Strain simulations in Additive Print



When to Calibrate

The values for SSF and ASCs depend upon many variables from both fabrication and simulation setup:

- Material
- Laser-PBF machine
- Process parameters (laser power, scan speed, layer thickness, baseplate temperature, hatch spacing, slicing stripe width, scan pattern, etc.)
- Simulation type performed (Assumed Strain, Scan Pattern, or Thermal Strain)
- Stress mode selected (linear elastic or J2 plasticity)

Assuming you perform the full procedure, for each calibration you will have a complete set of values to be used for any simulation type/stress mode *for a given material and machine*. When a different material or machine is chosen, the ASC and SSF values will need to be recalibrated, regardless of the simulation type or stress mode. Even changing the material *supplier* for a material you have already calibrated for may require a new calibration. If the process parameters are altered, Assumed Strain and Scan Pattern simulations will need to be recalibrated.

Important:

You need to calibrate only for the type of simulation you will be performing. For example, if you know you will be performing Assumed Strain simulations only, you don't need to build multiple calibration parts because scan patterns are not considered in this case, and you don't need to complete the calculations for ASCs, as those factors are required only for Scan Pattern and Thermal Strain simulation types. Within your Assumed Strain simulations, if you know you will be using linear elastic stress mode only, there is no need to calibrate for J2 plasticity. See the ANSYS Additive User's Guide for further information about simulation types and stress modes.

Matrix of SSF and ASCs

Figure 3 (p. 5) shows a complete matrix across different simulation types and stress modes for a certain material (Material A) and machine (Machine XYZ). After the full calibration process, you will record final values that are unique to that material and machine.

Figure 3: Complete matrix of SSF and ASCs for Machine XYZ

Material	Stress Mode	Assumed Strain Sim		Scan Pattern Sim		Thermal Strain Sim	
Material A	Linear Elastic	SSF		SSF		SSF	
				ASC ∥		ASC ∥	
				ASC ⊥		ASC ⊥	
				ASC z	1.000	ASC z	1.000
	J2 Plasticity	SSF		SSF		SSF	
				ASC ∥		ASC ∥	
				ASC ⊥		ASC ⊥	
				ASC z	1.000	ASC z	1.000

Overview of Procedure

The detailed calibration procedure consists of these steps: determining a calibration part, building parts, taking measurements, running simulations, calculating factors using a spreadsheet, and saving your custom material.

You will start by selecting or designing a calibration part that represents the distortion characteristics of your real production part.

Depending on whether you will use Assumed Strain or Scan Pattern/Thermal Strain simulation type, you will build either one part (for Assumed Strain) or multiple identical parts using a different scan pattern for each (for Scan Pattern and Thermal Strain).

Obtain the distortion measurements for each calibration part you build.

For Assumed Strain simulations, you will need only one part to determine the SSF value based on the measured distortion.

For Scan Pattern and/or Thermal Strain simulations, you will determine an initial set of SSF and ASC values using distortion values from the first two scan patterns, and then fine-tune the SSF values with the distortion value from a third scan pattern. Our experience shows that the third scan pattern calibration step increases the accuracy of simulations. We strongly recommend the fine-tuning step that uses the third scan pattern.

Determine Your Calibration Part

In many cases, it is time and cost prohibitive to go through trials and errors fabricating your real productions parts due to their size and complex structures. To perform the calibration, you will probably need to use a simplified geometry.

Choosing a good calibration geometry is critical for a successful calibration process. Since distortion can behave differently with respect to specific geometrical features, we highly recommend that you design your own calibration geometry. ANSYS Additive Print provides great flexibility to use any geometry for this calibration process.

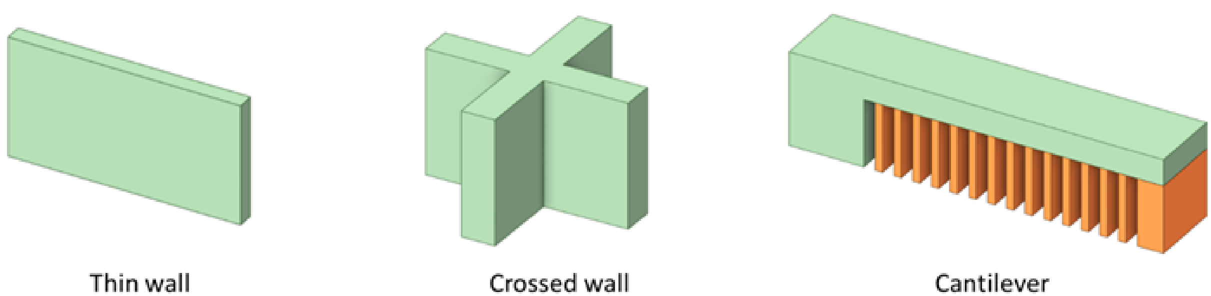
Consider the following aspects when selecting or designing a calibration geometry: geometrical features, distortion magnitude, buildability, simulation efficiency, and aspect ratio (for Scan Pattern and Thermal Strain simulation types).

Geometrical Features

Examine the production part that you plan to fabricate. Identify the area or feature that you care about the most as it relates to expected distortion. Based on the geometrical features, try to devise a simplified geometry that best represents the identified feature. The closer your calibration geometry is to the real production part feature of interest, the more applicable the calibrated SSF values are to your real production part.

For example, if you care most about the distortion in a thin feature on your real production part, then choose a thin wall or crossed wall geometry as a calibration geometry. In other cases where overhang may be more of a concern to you, cantilevers may be more favorable for your calibration.

Figure 4: Different calibration geometries for different distortion types



Distortion Magnitude

Due to the relatively large surface roughness found in parts fabricated using the laser-PBF process, you may have to consider creating a noticeable distortion when designing your calibration parts.

A general rule of thumb is to make sure the distortion values captured from experiments are at least one magnitude higher than the surface roughness of the part surface you measure. This will ensure a good signal-to-noise ratio, thus improving the confidence of the experimental results. For example, if the surface roughness is about 20 μm on the surface where you will take the measurement, target about 200 μm for the distortion magnitude.

In addition, as distortion magnitude can be very different among different materials, you may consider scaling up your calibration geometry to achieve the best distortion results.

Buildability

If you plan to measure on-plate distortion for calibration, consider focusing on the in-plane distortion instead of distortion along the vertical build direction. This will help reduce the possibility of any plastic deformation caused by blade dragging or blade crash during the fabrication process.

If you plan to measure distortion after cutoff of supports (support-only cutoff) for calibration, the buildability is less restrictive to you. However, post-processing typically is more time consuming and costly. It will also introduce more variables into the physics phenomena during the cutoff process. *Therefore, we recommend you consider on-plate distortion for calibration whenever possible.*

Simulation Efficiency

Element size for your simulation should also be considered when selecting or designing your calibration geometry. The Additive application uses the same size element throughout the entire model in a simulation. The element is a cubic voxel with a user-specified Voxel Size. Specifying voxel size can be a tricky balance between choosing a size small enough to ensure a converged solution in the feature where you will measure distortion, and yet large enough that the simulation does not take too long, when considering the overall number of elements needed for the entire part. When designing your calibration part, take care to ensure the feature of interest is large enough compared to the overall dimension of the calibration part for a reasonable voxel size. Doing so will help shorten the simulation time per iteration, thus speeding up the overall calibration process.

In some cases, the size of the calibration part may need to be scaled up in order to achieve suitable voxel sizes for both the calibration part and the part of interest.

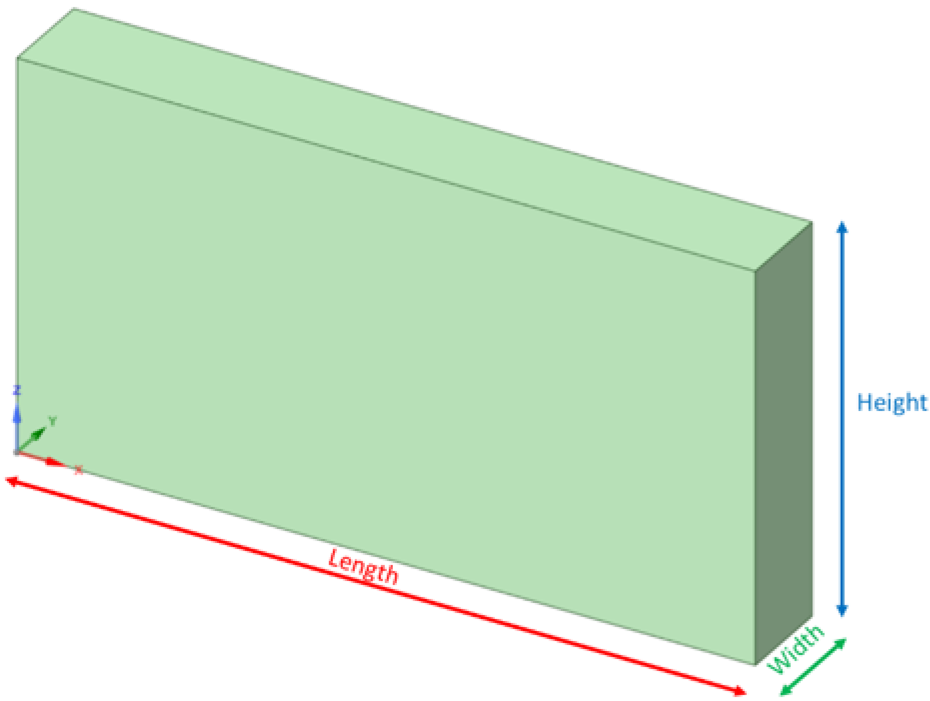
In addition, a tall part means more layers are needed for simulation. To help improve the simulation efficiency, treat calibration part height as a constraint during the part design stage.

Aspect Ratio (for Scan Pattern/Thermal Strain Simulation Types Only)

Since both Scan Pattern and Thermal Strain simulation types consider the strain anisotropy in the x, y and z directions of a part, you will need to use two scan patterns, one with a laser scan parallel to the part length direction (x-axis direction in your part CAD file) and the other with a laser scan parallel to the part width direction (y-axis direction in your part CAD file). Figure 5 (p. 9) shows an example calibration part with length, width, and height dimensions.

To differentiate the effect of a directional distortion distribution caused by a scan pattern effect, we recommend that you design your part with a longer length (in x-direction) and a shorter width (in y-direction) to increase the length-to-width aspect ratio.

Figure 5: Calibration part example dimensions



To get you started, some example parts with different features are available for download (thin wall, cross wall, cantilever, 4pillars, and double arch). However, it is best to design your own calibration part that reflects the distortion feature you care about the most in your production parts.

Build the Calibration Parts

Our recommendations for building the calibration parts are provided for the following topics.

Machine Calibration and Maintenance

A laser-PBF machine may degrade over time and typically needs regular maintenance. To avoid degraded laser and optical performance, we recommend you calibrate your machine prior to building any Additive calibration parts. Such a process includes, but is not limited to, checking that laser parameters such as power, scan speed, and beam diameter are within specification, and running a machine calibration build to ensure the as-built geometry dimensions are as close to the nominal CAD file dimensions using the default process parameters. Refer to the documentation from your machine.

Part Layout

- Build several replicas of the calibration parts in case build failures occur.
- Build all calibration parts on the same build plate.
- Implement an appropriate layout consistent with the best practice for taking gas flow direction and recoating direction into account.
- Ensure there is enough space between the parts to take measurements *before the parts are cut from the baseplate*.

Process Parameters

With the exception of the scan patterns that are described next, the calibration geometries and its support (if any) should be built with the process parameters (laser power, scan speed, beam diameter, etc.) that you intend to use when building your real production parts.

In order to improve the surface quality of the printed calibration geometry as well as to maintain the closest dimensional match to the nominal CAD file, we recommend you apply the default contour parameters and calibrated shrinkage factors for all directions for fabrication.

Scan Patterns

Two angle values are used to define a scan pattern, namely starting layer angle and layer rotation angle. They are described in a format of (starting layer angle, layer rotation angle) in this guide. For example, (0, 67) means a scan pattern with a 0° starting layer angle and a 67° layer rotation angle.

The **starting layer angle** is the angle at which the first layer will be scanned. It is measured from the X axis, such that a value of 0° results in scan lines parallel to the X axis. In this guide, the X-axis is parallel to your calibration part length. If your machine uses a different coordinate system, make sure that a scan pattern (0, 0) results in the laser scan direction parallel to the length of your calibration part.

The **layer rotation angle** is the angle at which the major scan vector orientation changes from layer to layer.

Note that both angles refer to the direction of the laser scan vector, not the stripe direction.

To visualize the scan patterns, we'll use the example geometry shown in Figure 5 (p. 9) for demonstration. Build the calibration parts with the scan patterns as shown in the following figures. (For Assumed Strain simulations, only scan pattern 3 is needed.)

- Scan pattern 1: bi-directional scan with (0, 0) scan pattern. The actual laser scan vectors should be parallel to the part length direction from the first layer to the completion of the build. See Figure 6 (p. 12).
- Scan pattern 2: bi-directional scan with 90° starting angle and 0° layer rotation angle, scan line is either 90° or 270°. The actual laser scan vectors should be orthogonal to the part length direction (parallel to part width direction) from the first layer to the completion of the build. See Figure 7 (p. 13)
- Scan pattern 3: use the scan pattern that you intend to use for building your real production part. In this guide, we use a rotating (0, 67) scan pattern as an example. The actual laser scan vectors for (0, 67) should be bi-directional scans parallel to the part length direction for the first layer. Starting the second layer, there is a 67° rotation counterclockwise from the previous layer scan direction per layer until completion of the build. See Figure 8 (p. 13)

Figure 6: Scan pattern 1 (0°, 0°)

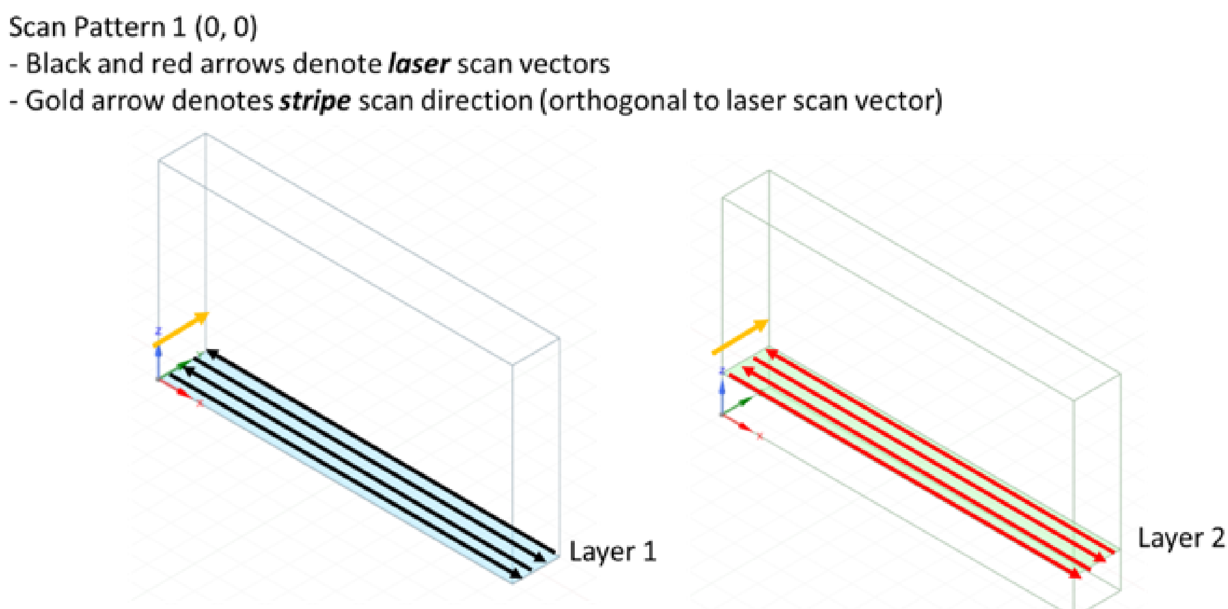


Figure 7: Scan pattern 2 (90°, 0°)

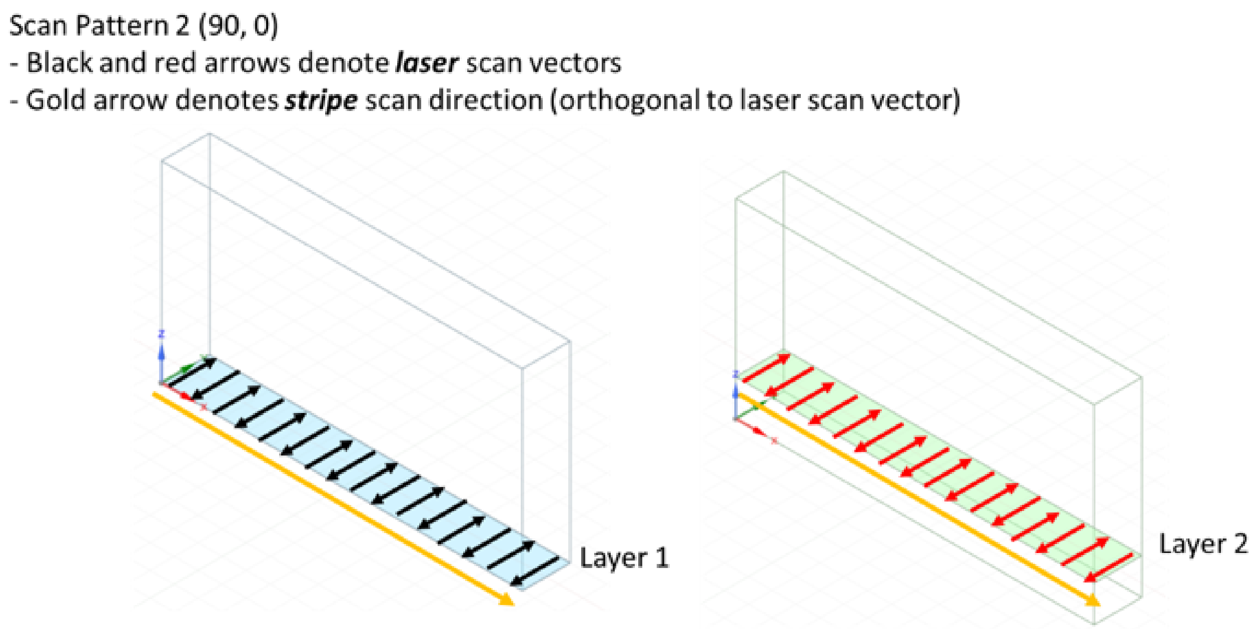
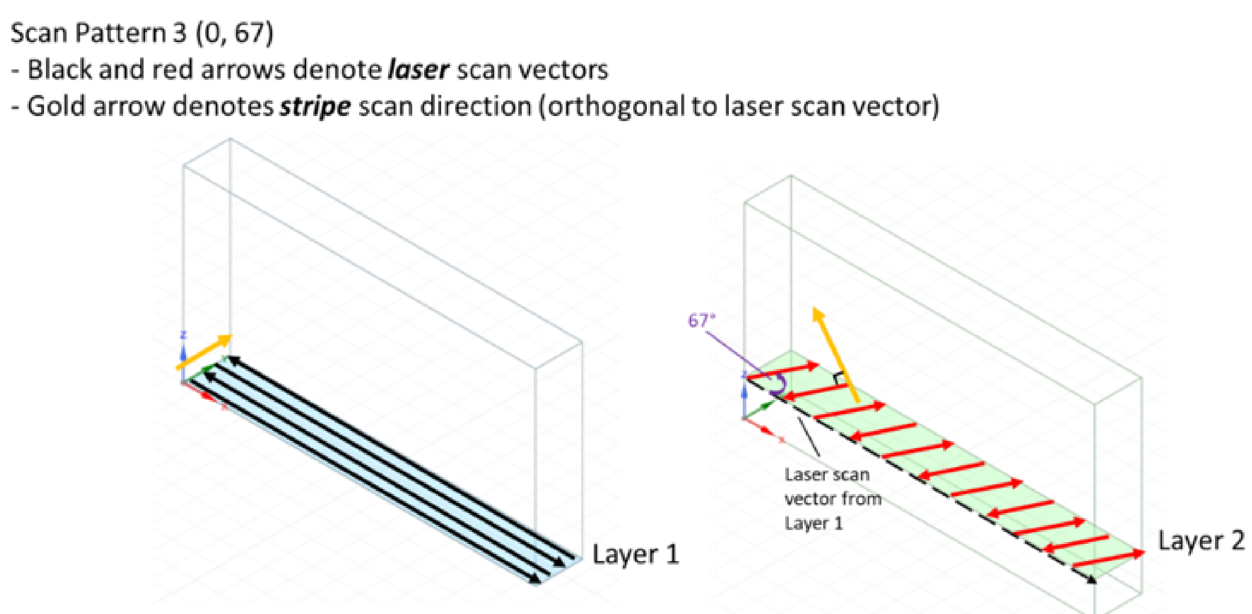


Figure 8: Scan pattern 3 (rotating)



Take Distortion Measurements

Using the best measurement method available, measure the dimensions of the calibration parts at the location of interest and calculate its corresponding distortion values by comparing the actual dimension to the nominal CAD file dimension. Record the experimental distortion in the Ansys-provided calibration spreadsheet.

Measurement Locations

Measure at the locations where noticeable distortions take place with a decent signal-to-noise ratio.

Avoid measurement locations that exhibit significant buckling.

You can measure either on-plate distortion or distortion after cutoff of supports (support-only cutoff, the part is still attached to the base plate).

Our experience has shown that even though the on-plate distortion may be a little difficult to measure for some material types due to a lower signal-to-noise ratio, on-plate distortion is usually much more sensitive to SSF. This means the SSF obtained from on-plate distortion is typically more accurate. Therefore, we recommend you use on-plate distortion for calibration whenever possible.

Measurement Methods

Several measurement methods are available and are described below. Choose a measurement technique with the best resolution available.

CMM

If using a Coordinate Measurement Method (CMM), measure many points in a line along the chosen surface of the cantilever beam. Find the maximum deflection for the measurement location(s).

Record the value of the dimensions on the spreadsheet provided by ANSYS.

Laser Scanner

If using a laser scanner, point cloud or scanned STL file can be obtained. We recommend you scan the entire calibration geometry without coating the anti-reflective agent to avoid introducing measurement noise. After obtaining the point cloud data, post process it to find the maximum deflection for the measurement location(s).

Caliper/Micrometer and a Digital Height Gage

If using a caliper/micrometer, we recommend using calipers with fine detail extensions and a digital height gage to mark the height. Measure the dimension of your calibration geometry at the locations of interest to find the maximum deflection. This measurement technique is less accurate than the other methods and may result in inaccurate distortion. Therefore, this is the least preferred measurement method.

As a last resort, if you do not have a digital height gage, you may want to consider modifying the .stl file to include detents at the location of interest and then use this modified geometry in your simulations.

Run the Simulations

For a chosen combination of simulation type (Assumed Strain, Scan Pattern, or Thermal Strain) and stress mode (Linear Elastic or J2 Plasticity), run simulations of the calibration part in Ansys Additive Print.

Below are some important considerations when you set up the calibration simulations for all simulation type and stress mode combinations. Keep these settings consistent for all calibration simulation iterations.

Voxel Size

Since your calibration geometry represents the distortion feature from your real production part, for best results, we recommend that you use the same voxel size for both calibration and your real production part simulations. The calibrated SSF and ASCs should be directly applicable to your real production part distortion simulation if the same voxel size is maintained.

In general, the smaller the voxel size, the easier it is to reach to a converged distortion output. A rule of thumb is that there should be eight voxels or more through the feature thickness where you plan to extract distortion results. In some cases where your part is very large, however, you may need to increase the voxel size to ensure a practical simulation time.

Distortion Data Extraction Location

The ideal location to extract distortion results is at a location with fully dense voxels in the simulation model. For details, refer to Voxel Sample Rate in the *Additive User's Guide (Print and Science)*.

Material Properties

You can use material properties either from an ANSYS-predefined material or your customized material. If you have trusted material properties obtained from experiments, we recommend you use the experimentally determined material properties.

Running the Simulations

Assumed Strain Simulation Type:

- For both linear elastic and J2 plasticity, start with the SSF_0= 1
- Use scan pattern 3 (Figure 8 (p. 13))

Scan Pattern/Thermal Strain Simulation Types:

- Start with the default SSF_0= 1 and default ASC_0 = (1.5, 0.5, 1)
- Run simulations with scan patterns 1 (0,0) and 2 (90,0) (Figure 6 (p. 12) and Figure 7 (p. 13))

- Fine-tune the SSF using the third scan pattern. Start with the calibrated SSF from the first step. Fix with calibrated ASCs from the first step.
- Run simulations with scan pattern 3 (0,67) and adjust SSF accordingly (Figure 8 (p. 13))

Extracting Distortion Simulation Data

You can use either on-plate distortion or support-only cutoff distortion simulation results for the calibration process. However, on-plate distortion is preferable since on-plate distortion is usually much more sensitive to SSF. This means the SSF obtained from on-plate distortion is typically more accurate. Therefore, we recommend you use on-plate distortion for calibration whenever possible.

- On-plate distortion results are included by default in Outputs during the simulation setup.
- Select the Displacement after cutoff > Support-only Cutoff > Instantaneous in Outputs during the simulation setup to include support-only cutoff distortion results.

Once the simulation is completed, you can use either the built-in Ansys viewer or another viewer application, such as Ansys EnSight or ParaView, to view and process the directional component of displacement at the location of interest that corresponds to your experimental measurements.

ParaView is an open-source, multi-platform data analysis and visualization application. Within ParaView, extract the distortion data by doing the following:

Open the appropriate files and make it active.

Edit > Find Data...

Figure 9: Example of how to use ParaView to find displacement value

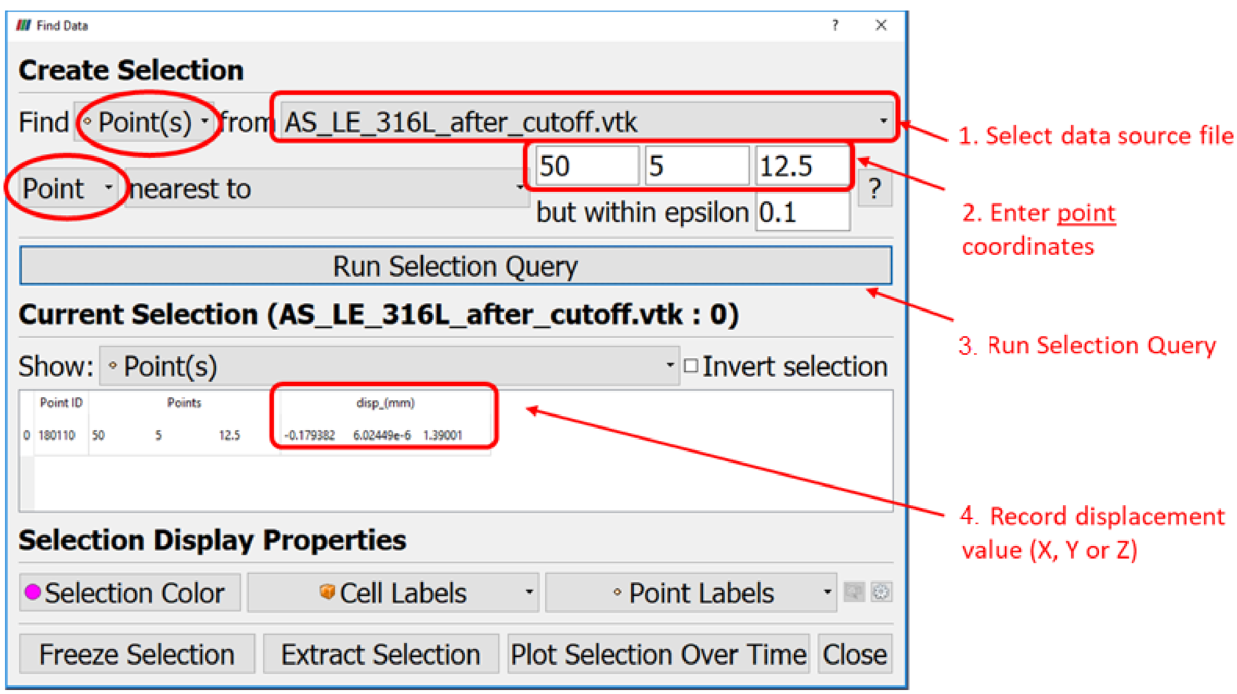
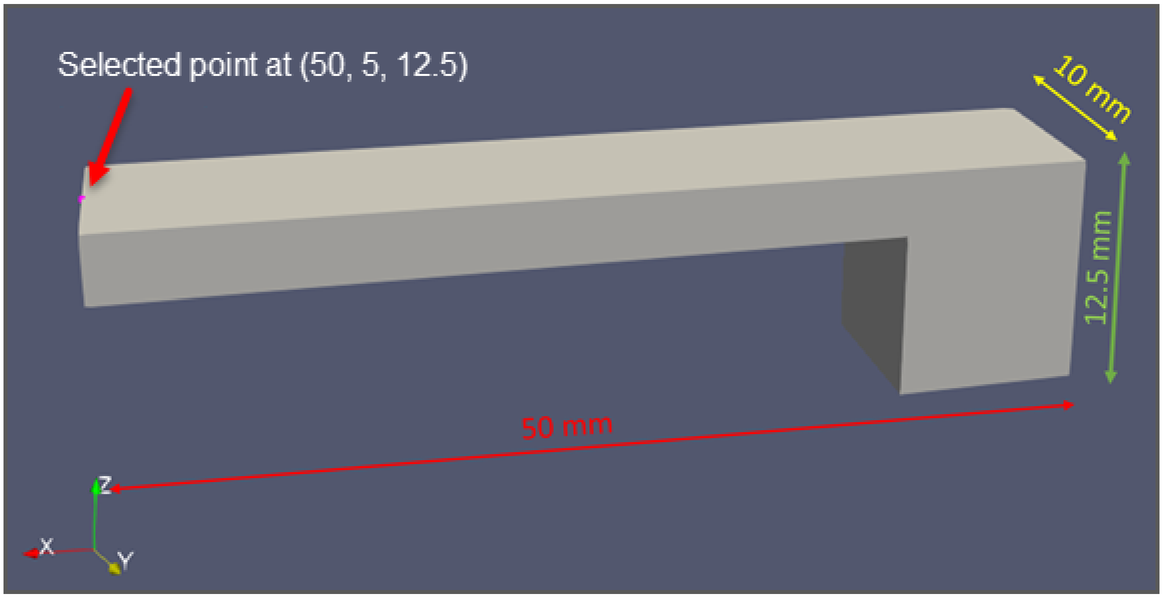


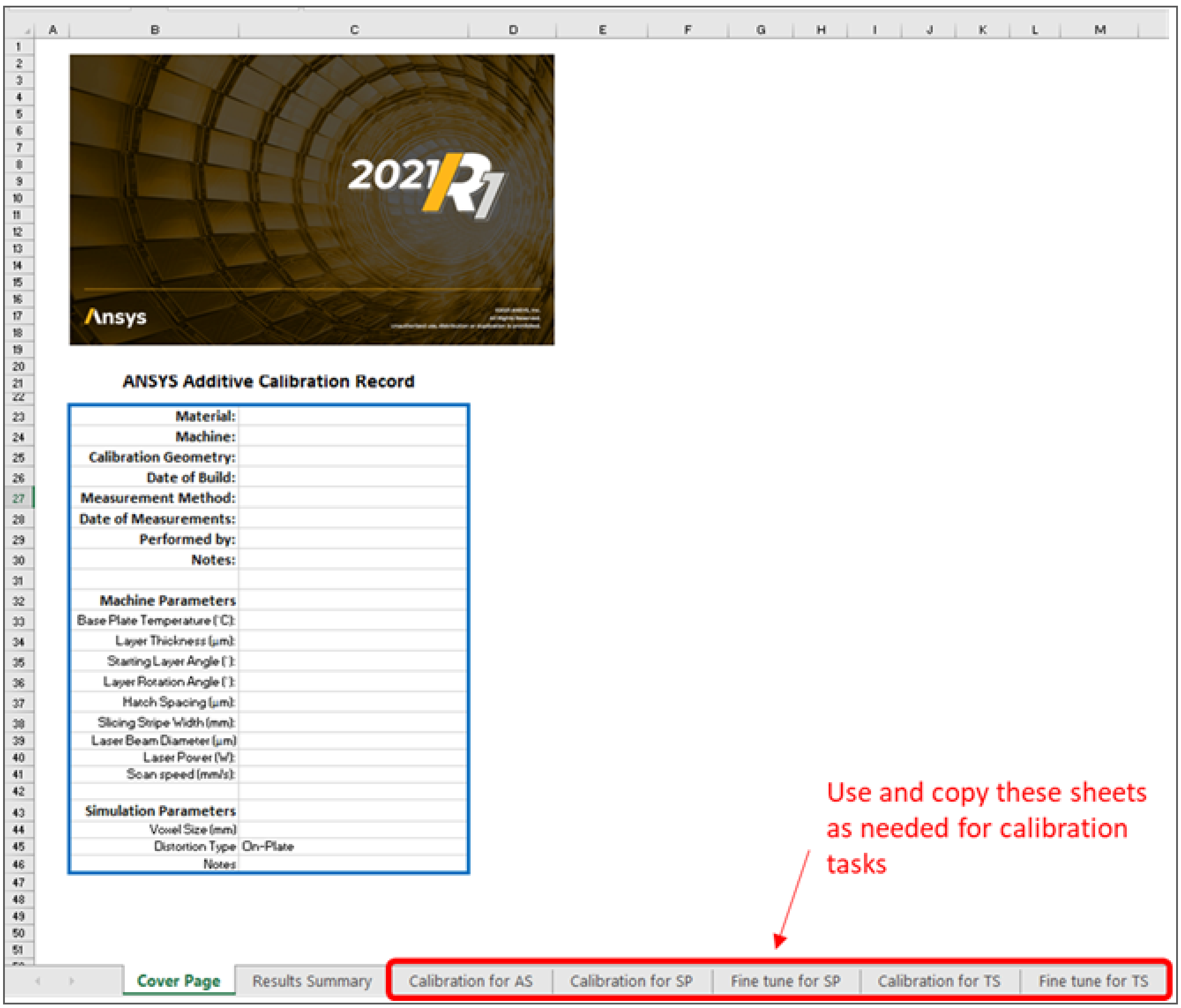
Figure 10: Point highlighted after using the "Find Data" query



Calculate SSF and ASCs Using the Spreadsheet

An easy-to-use, customized spreadsheet (.xlsx file) is available to calculate the Strain Scaling Factor (SSF) and the Anisotropic Strain Coefficients (ASCs). (The spreadsheet is available for download here.) Tabs at the bottom of the spreadsheet (**Calibration for AS**, **Calibration for SP**, and **Calibration for TS**) represent the three different simulation types.

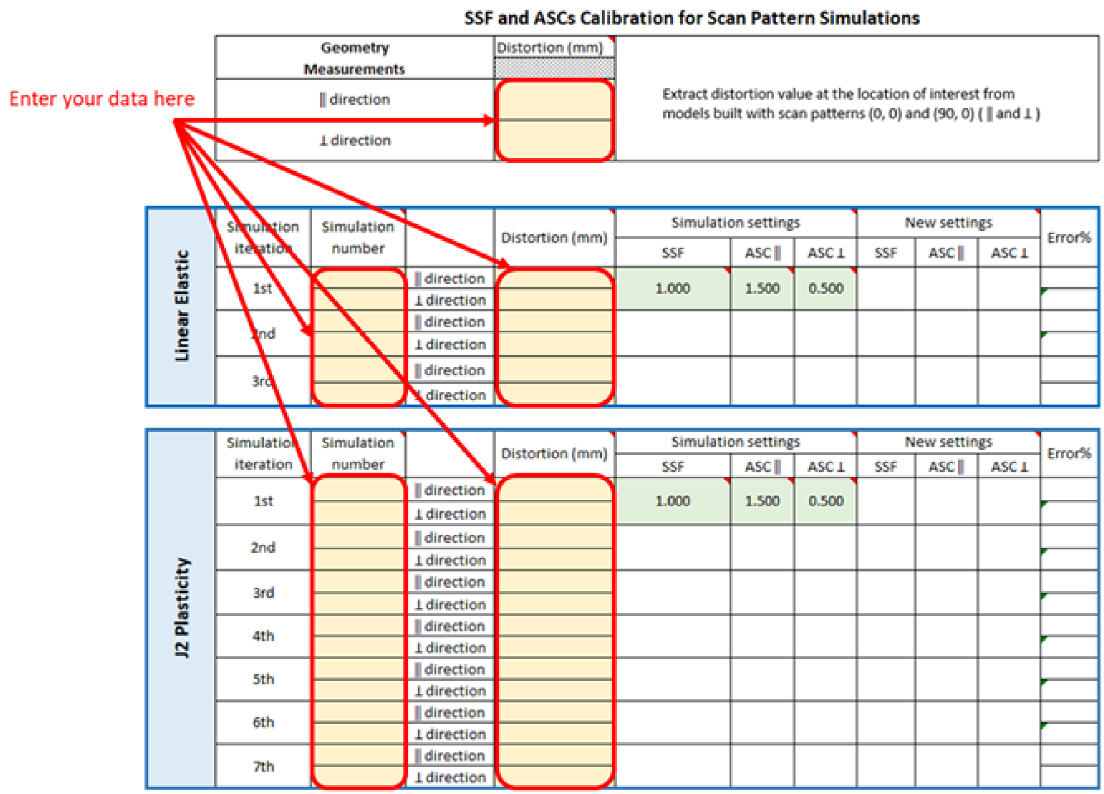
Figure 11: Calibration spreadsheet



The sheets are designed so that you enter your own data in the colored-filled cells and the corresponding values for SSF and ASCs will automatically be calculated based on formulas locked into the spreadsheet.

Sample values are included in the colored cells just as an example, so the first thing to do is clear the sample data.

Figure 12: Entering data in the calibration spreadsheet



1. **Run first calibration set to determine an initial set of factors (for each simulation type and stress mode combination)**

   For a chosen combination of simulation type and stress mode, run simulations of the calibration part in Additive Print. Use the spreadsheet to calculate factors.

   a. In Additive Print, run a simulation of the calibration part using *default SSF and ASCs*.

   b. Using the spreadsheet, calculate new SSF and ASCs using simulation distortion data compared to measured distortion data from the calibration part. (This is done automatically with formulas built into the spreadsheet.) This is the first iteration.

Figure 13: First simulation iteration in Scan Pattern example

SSF and ASCs Calibration for Scan Pattern Simulations

Geometry Measurements	Distortion (mm)	
‖ direction	0.261	Extract distortion value at the location of interest from models built with scan patterns (0, 0) and (90, 0) (‖ and ⊥)
⊥ direction	0.129	

Linear Elastic	Simulation iteration	Simulation number		Distortion (mm)	Simulation settings SSF	Simulation settings ASC ‖	Simulation settings ASC ⊥	New settings SSF	New settings ASC ‖	New settings ASC ⊥	Error%
	1st	03-978	‖ direction	0.262	1.000	1.500	0.500	1.088	1.338	0.662	0.3%
		04-1469	⊥ direction	0.096							25.2%
	2nd		‖ direction		1.088	1.338	0.662				
			⊥ direction								
	3rd		‖ direction								
			⊥ direction								

c. Run simulations using calculated SSF and ASCs, and then iterate until the new SSF and ASCs converge to an acceptable level of error between measured and simulated distortion.

Figure 14: Second simulation iteration in Scan Pattern example

SSF and ASCs Calibration for Scan Pattern Simulations

Geometry Measurements	Distortion (mm)	
‖ direction	0.261	Extract distortion value at the location of interest from models built with scan patterns (0, 0) and (90, 0) (‖ and ⊥)
⊥ direction	0.129	

Linear Elastic	Simulation iteration	Simulation number		Distortion (mm)	Simulation settings SSF	Simulation settings ASC ‖	Simulation settings ASC ⊥	New settings SSF	New settings ASC ‖	New settings ASC ⊥	Error%
	1st	03-978	‖ direction	0.262	1.000	1.500	0.500	1.088	1.338	0.662	0.3%
		04-1469	⊥ direction	0.096							25.2%
	2nd	03-979	‖ direction	0.256	1.088	1.338	0.662	1.088	1.338	0.662	1.8%
		04-1470	⊥ direction	0.134							3.7%
	3rd		‖ direction		1.088	1.338	0.662				
			⊥ direction								

2. **Run fine-tuning calibration step with a different scan pattern**

   a. In Additive Print, run a simulation of the calibration part using a rotating scan pattern and the *calibrated SSF and ASCs*.

Figure 15: Scan Pattern example (first simulation iteration for rotating pattern)

SSF and ASCs Additional Calibration for Scan Pattern Simulations

Geometry Measurements	Distortion (mm)	
Rotating stripe scan pattern (or user-customized)	0.221	Extract distortion value at the location of interest from models built with third scan pattern (rotating stripe)

	Simulation iteration	Simulation number	direction	Distortion (mm)	Simulation settings			New settings			Error%
					SSF	ASC ∥	ASC ⊥	SSF	ASC ∥	ASC ⊥	
Linear Elastic	1st	03-980	rotating	0.19	1.088	1.338	0.662	1.234	1.338	0.662	11.8%
	2nd		rotating		1.234	1.338	0.662				
	3rd		rotating								

b. Run simulations using the newly-calculated SSF and then iterate until the new SSF converges to an acceptable level of error between measured and simulated distortion.

Figure 16: Scan Pattern example (next simulation iterations for rotating pattern)

SSF and ASCs Additional Calibration for Scan Pattern Simulations

Geometry Measurements	Distortion (mm)	
Rotating stripe scan pattern (or user-customized)	0.221	Extract distortion value at the location of interest from models built with third scan pattern (rotating stripe)

Calibrated SSF and ASCs

	Simulation iteration	Simulation number	direction	Distortion (mm)	Simulation settings			New settings			Error%
					SSF	ASC ∥	ASC ⊥	SSF	ASC ∥	ASC ⊥	
Linear Elastic	1st	03-980	rotating	0.19	1.088	1.338	0.662	1.234	1.338	0.662	11.8%
	2nd	03-981	rotating	0.22	1.234	1.338	0.662	1.230	1.338	0.662	0.3%
	3rd	03-982	rotating	0.22	1.230	1.338	0.662	1.235	1.338	0.662	0.5%

c. Record the final SSF and ASCs in a table such as the one shown in Figure 3: Complete matrix of SSF and ASCs for Machine XYZ (p. 5).

Figure 17: Final calibration results in spreadsheet

Summary of calibrated SSF and ASCs for specific stress mode and simulation type combinations

Summary of Results

Material	Stress Mode	Assumed Strain		Scan Pattern		Thermal Strain	
316L	Linear Elastic	SSF		SSF	1.234	SSF	
				ASC ∥	1.338	ASC ∥	
				ASC ⊥	0.662	ASC ⊥	
				ASC_z	1.000	ASC_z	1.000
	J2 Plasticity	SSF		SSF		SSF	
				ASC ∥		ASC ∥	
				ASC ⊥		ASC ⊥	
				ASC_z	1.000	ASC_z	1.000

Use this sheet to summarize the results of your calibration. These values of SSF and ASCs are valid for ANSYS Additive simulations using the same material and machine with which the calibration was performed.

Other Considerations

The distortion values seen in the provided spreadsheets are for demonstration purposes only. Distortion values will vary based on material, machine, and process parameters.

You will need to copy calibration sheets for other simulations.

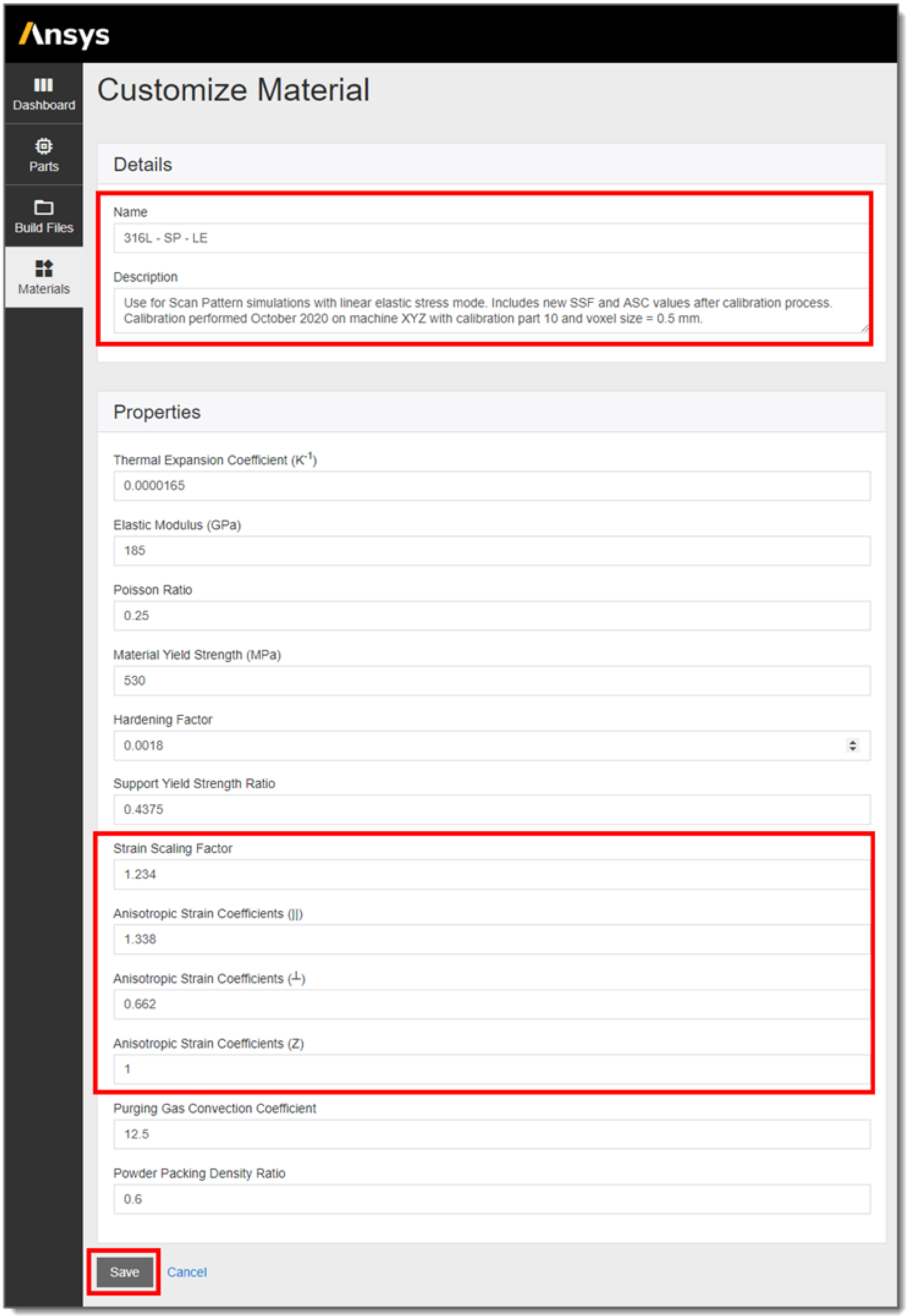
Save Your Final Results as a Custom Material

The calibration process is complete when you have obtained values for SSF and ASCs that are within an acceptable level of error between measured and simulated distortion. Because the goals of every company and the design of every manufactured part are unique, it is up to you to decide what is an acceptable level of error. Record the final values in the Results Summary sheet in the spreadsheet. (The Results Summary sheet is the same as shown in Figure 3 (p. 5) in this guide.) Then use those new values of SSF and ASCs for all your simulations in Additive Print for that machine and material.

Within Additive Print, we recommend you save the final SSF and ASCs by creating customized materials for each material/simulation type/stress mode combination.

In the Materials library, select your material and then click Customize. This brings up an edit panel where you can change the SSF and ASC values to the final calibrated values. Then be sure to select the appropriate custom material when performing future simulations.

Figure 18: Saving calibration results as custom material



Appendix A. Equations for Calculating SSF and ASCs

The equations used in the ANSYS-provided spreadsheet (p. 21) for calculating the Strain Scaling Factor (SSF) and Anisotropic Strain Coefficients (ASCs) are shown here for reference.

For an overview of the calculation process, see Process Flow for the SSF and ASCs Calculations (p. 32).

Nomenclature

The equations in this appendix use the following standard nomenclature:

Variable	Meaning
δe	Experimental distortion
δs	Simulation distortion
r	Ratio

Subscript	Meaning
$\|\|$	Parallel to the scan direction
$\perp$	Perpendicular to the scan direction
$n-1$	Setting before the most recent iteration
n	Setting of the most recent iteration
$n+1$	Setting for the next iteration
0, 1, 2, ...	iteration 1, iteration 2, iteration 3, …
m	Modified version

Linear Elastic Stress Mode Calculations

Assumed Strain SSF

$$SSF_{new}=\frac{\delta e}{\delta s}\bullet SSF_{old}$$

Scan Pattern / Thermal Strain SSF

$$SSF_{new}=\frac{\delta e_{||}+\delta e_{\perp}}{\delta s_{||}+\delta s_{\perp}}\bullet SSF_{old}$$

Scan Pattern / Thermal Strain ASCs

$$ASC_{||}=\frac{2}{\left(1+\frac{\delta e_{\perp}}{\delta e_{||}}\right)}$$

$$ASC_{\perp}=2-ASC_{||}$$

Plasticity Stress Mode Calculations

Follow these steps to perform the plasticity stress mode calculations:

Step 1: Set the First Iteration of Simulations

Set the first iteration of simulations using these defaults:

- Assumed Strain simulation: $SSF_0=1$
- Scan Pattern / Thermal Strain simulation: $SSF_0=1$, $ASC_{||0}=1.5$, and $ASC_{\perp 0}=0.5$

For Assumed Strain simulation, extract target distortion value δs_0.

For Scan Pattern / Thermal Strain simulation, extract target distortion value $\delta s_{0||}$ from one simulation, and $\delta s_{0\perp}$ from a second simulation.

Step 2: Calculate the New SSF and ASCs

Calculate the new SSF and ASCs after the first iteration:

Assumed Strain

$$SSF_1=(\delta e/\delta s_0)SSF_0$$

Scan Pattern / Thermal Strain

Calculate the average value of distortion in the parallel and perpendicular directions after the first distortion:

$$avg(\delta)=\frac{\delta_{||}+\delta_{\perp}}{2}$$

Calculate SSF and ASC in the second iteration by:

$$SSF_1=SSF_0\frac{avg(\delta e)}{avg(\delta s_0)}$$

$$ASC_{||1}=(2-ASC_{||0})\left(\frac{\delta e_{||}+\delta s_{\perp}}{\delta e_{\perp}+\delta s_{||}}-1\right)+ASC_{||0}$$

Step 3: Determine Whether the New SSF Is < 1 or $\geq$ 1

If the suggested new SSF_1 is less than 1, set SSF_{1m} = 0.002 and run the simulation to extract δs_1.

If the suggested new SSF_1 is grater than or equal to 1, set $SSF_{1m} = SSF_1$ and run the simulation to extract δs_1.

Step 4: Perform Linear Interpolation Between Iterations 1 and 2

Perform linear interpolation between the iteration 1 (default value) and iteration 2 to extract SSF_2, ASC_2, and the values for the subsequent iterations.

For SSF_{1m} = 0.002 (SSF_1 < 1)

1. $SSF_2 = \frac{(\delta e - \delta s_0)(SSF_1 - SSF_0)}{(\delta s_1 - \delta s_0)} + SSF_0$

2. Determine whether $avg(\delta s_1) < avg(\delta e) < avg(\delta s_2)$.

   If *Yes*:

   $$SSF_{n+1} = \frac{(\delta e - \delta s_1)(SSF_n - SSF_1)}{(\delta s_1 - \delta s_0)} + SSF_1, \ where\, n \geq 2$$

   If *No*:

   $$SSF_{n+1} = \frac{(\delta e - \delta s_0)(SSF_n - SSF_0)}{(\delta s_n - \delta s_0)} + SSF_0, \ where\, n \geq 2$$

For $SSF_{1m} = SSF_1$ (SSF1 $\geq$ 1)

$$SSF_{n+1} = \frac{(\delta e - \delta s_{n-1})(SSF_n - SSF_{n-1})}{(\delta s_n - \delta s_{n-1})} + SSF_{n-1}, \ where\, n \geq 1$$

For Both Cases

$$r = \frac{\delta s_{||}}{\delta_{\perp}} \qquad r_e = \frac{\delta e_{||}}{\delta e_{\perp}}$$

$$ASC_{||n+1} = \frac{(r_e - r_{n-1})(ASC_{||n} - ASC_{||n-1})}{(r_n - r_{n-1})} + ASC_{||n-1}$$

$$ASC_{\perp n+1} = 2 - ASC_{||n+1}$$

Step 5: Calculate the Relative Error

Calculate the relative error $\frac{|\delta s_{||n} - \delta e_{||}|}{\delta e_{||}}$, where n≥1 and $\frac{|\delta s_{\perp n} - \delta e \perp|}{\delta e \perp}$, where n≥1.

Determine whether the error exceeds your tolerance.

If *Yes*:

End the calibration program.

If *No*:

Go back to the iteration.

Figure 19: Process Flow for the SSF and ASCs Calculations