ANSYS Additive Calibration Guide

Applies to:

- ANSYS Additive Print
- ANSYS Additive Suite

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Objective

The objective of this Calibration Guide is to establish a procedure that you can easily follow to determine the Strain Scaling Factor (SSF) and Anisotropic Strain Coefficients (ASCs) for use in the ANSYS Additive Print software. The calibrated and validated SSFs and ASCs will significantly improve the prediction accuracy of the simulation software, thus improving the chance of successful builds as well as reducing the cost of trial and error experiments.

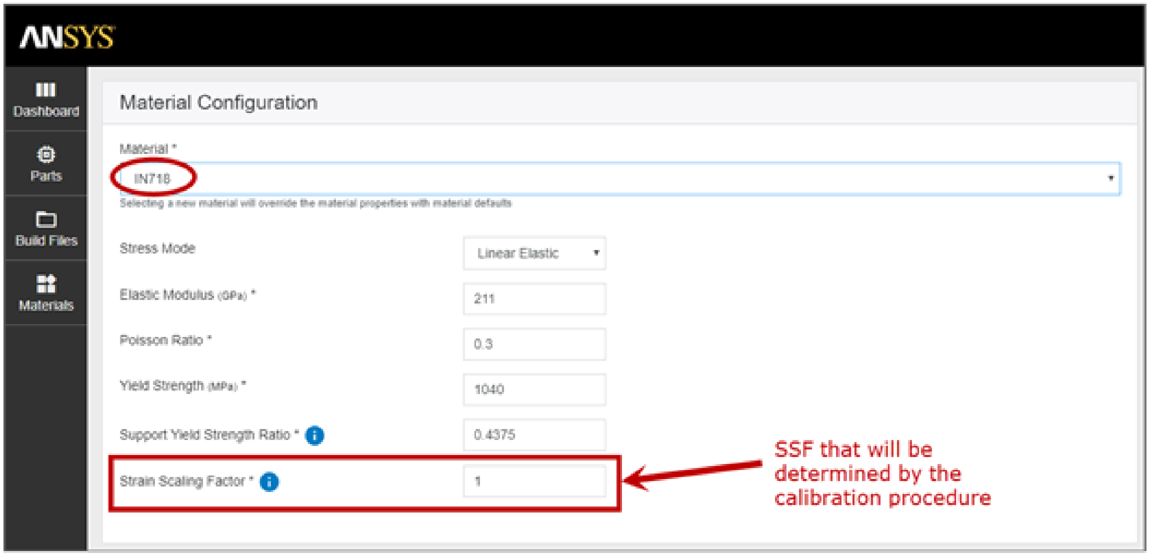


Figure 1: Additive Print application - SSF is required for Assumed Strain simulation type

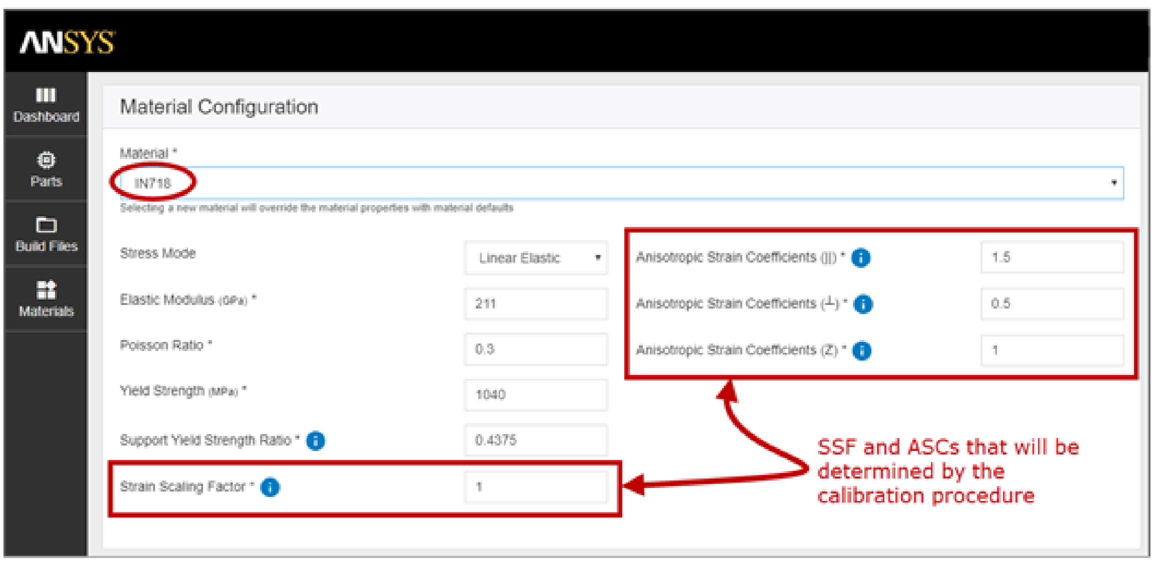


Figure 2: SSF and ASCs are required for Scan Pattern and Thermal Strain simulation types

Procedure

The process consists of a calibration step and a validation step. The calibration step determines an initial set of calibrated SSFs and ASCs. The validation step checks the calibrated values against a different geometry and/or scan pattern. Ideally, the set of SSFs and ASCs should be the same after the validation, but our experience has shown that a second geometry and/or scan pattern "fine-tunes" the values somewhat. While the validation step is optional, we strongly recommend it.

For the validation part(s), you may build representative geometries of your real component or build the validation part described in this guide. The list of validation geometries may be expanded and added to this guide as more test data becomes available.

The overall procedure involves the following steps:

1. **Build calibration and validation parts on the same build plate**

   For convenience, we recommend building all the parts on the same build plate. In this Calibration Guide, we use the same part for both the calibration and validation steps but use a different scan pattern for each. The dimensions of the part may be adjusted depending on the material, machine, and process parameters to achieve a successful build. The procedure remains the same regardless of part dimensions.

2. **Measure the dimensions of the built parts to determine distortion**

   Using the best measurement method available, measure the dimensions of the parts at the recommended locations of interest. Record the dimension measurements in the ANSYS-provided spreadsheet and distortions at those locations will automatically be calculated.

3. **Calibrate 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 provided to calculate factors.

   a. Run a simulation of the *calibration part* using *default* SSF and ASCs.

   b. 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.)

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

4. **Validate the factors (for that simulation type and stress mode combination)**

   a. Run a simulation of the *validation part* using the *calibrated* SSF and ASCs.

   b. Run simulations using the newly-calculated SSF and then continue to fine-tune new SSF values until answers converge to an acceptable level of error between measured and simulated distortion.

   c. Record the final SSF and ASCs in a table such as the one shown in Table 1.

When to Calibrate

The values for SSF and ASCs depend upon the following:

- Material
- Machine
- Machine parameters (laser power, scan speed, 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, a new calibration and validation will be necessary, 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-based simulations will need to be recalibrated and validated.

Important:

You need to calibrate only for the type of simulation you will be performing. For example, if you know you will be performing only Assumed Strain simulations, 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

Table 1 shows a complete matrix across different simulation types and stress modes for a certain material, A. After the full calibration process, you will record final (calibrated and validated) values in the color-filled fields that are unique to that material and machine.

Material	Stress Mode	Assumed Strain		Scan Pattern		Thermal Strain	
A	Linear Elastic	SSF		SSF		SSF	
				ASC ǁ		ASC ǁ	
				ASC ⊥		ASC ⊥	
				ASC_z	1	ASC_z	1
	J2 Plasticity	SSF		SSF		SSF	
				ASC ǁ		ASC ǁ	
				ASC ⊥		ASC ⊥	
				ASC_z	1	ASC_z	1

Table 1: Complete matrix of SSF and ASCs

Crossed Walls Geometry

Geometry files (.stl format) are available for download here.

A **crossed walls** part with dimensions of 60 x 60 x 40 mm (length x width x height) is shown in Figure 3a. The measurement location of interest is at the center of the wall face at **Z = 22 mm**, as shown in Figure 3b.

For the simulations, we suggest a **voxel size = 0.25 mm**.

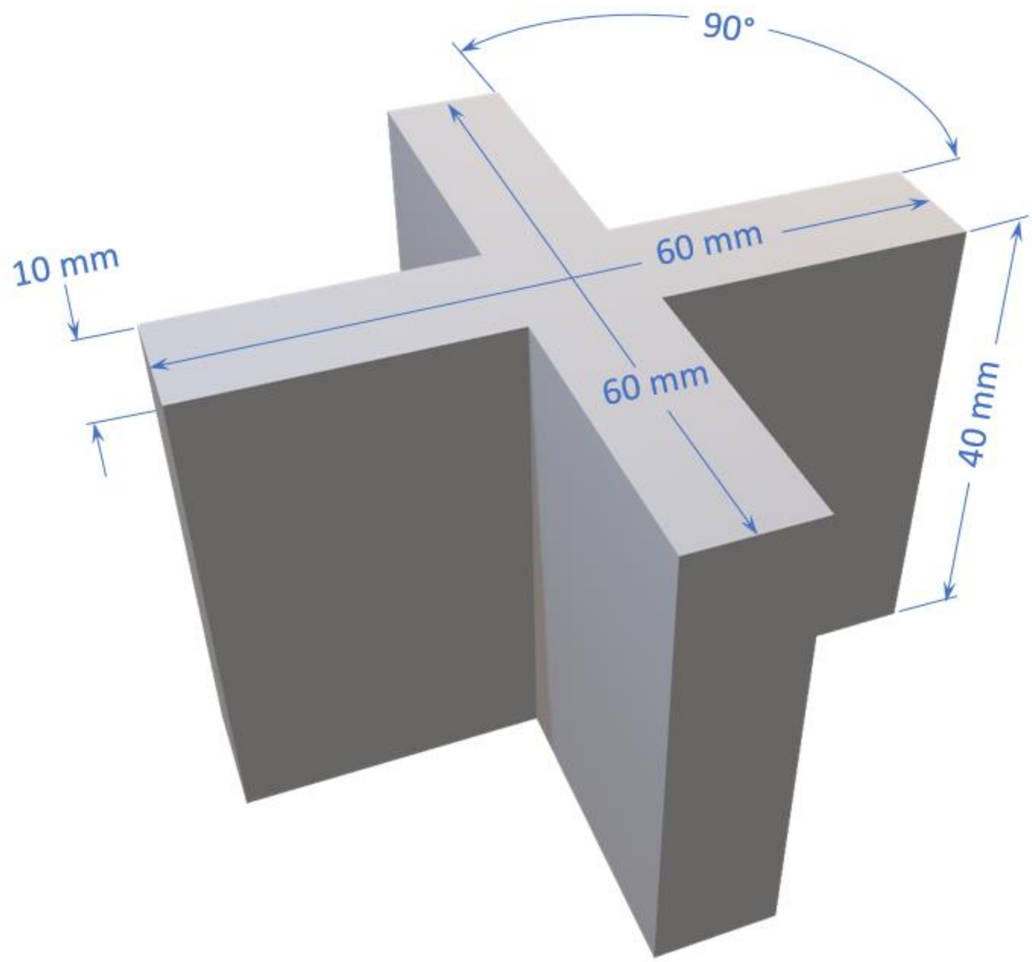


Figure 3a: Crossed walls part showing dimensions

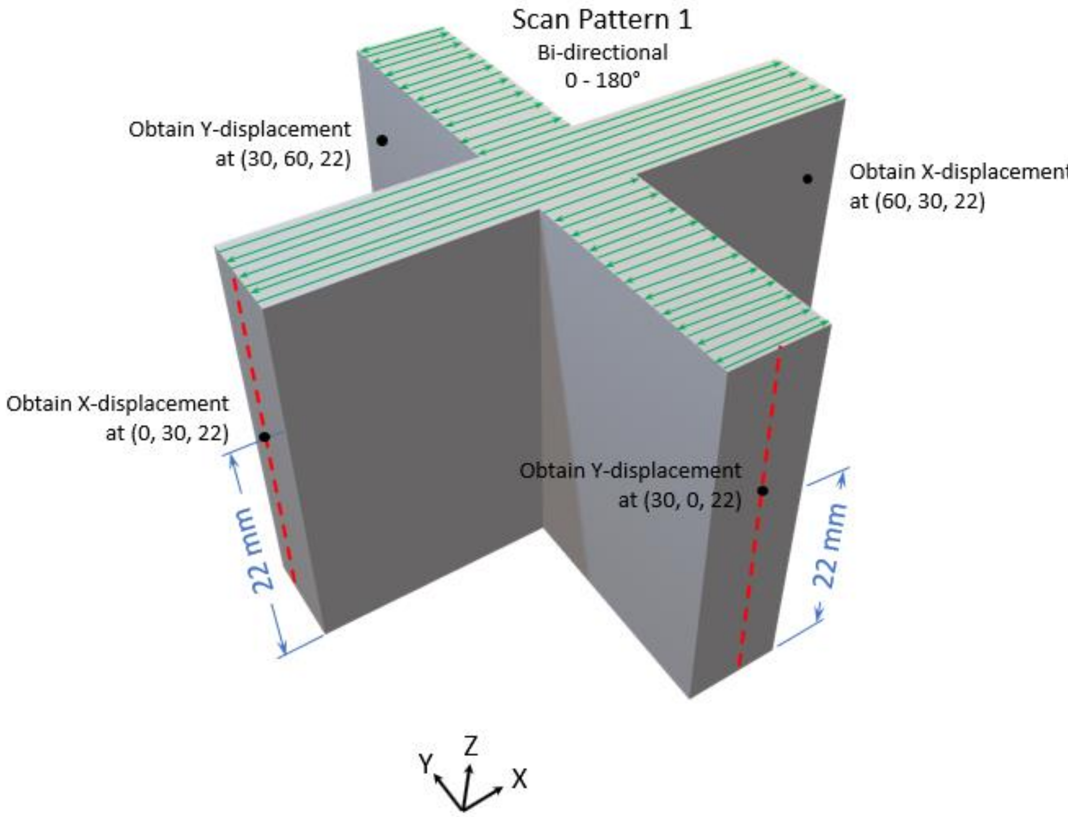


Figure 3b: ***Calibration part:*** *Crossed walls part with scan pattern 1 (bi-directional). Measurement locations also shown.*

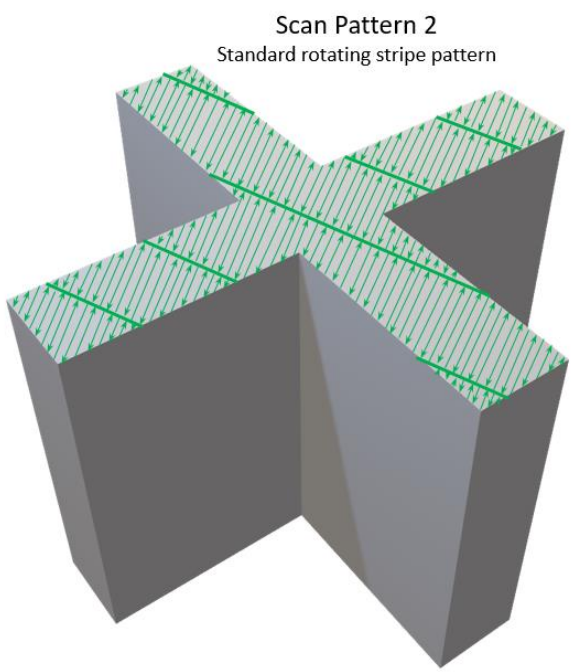


Figure 3c: ***Validation part:*** *Crossed walls part with scan pattern 2 (rotating stripe shown here)*

Building the Parts

Part Layout

We recommend you *build the calibration and validation parts on the same build*. There will be two crossed walls parts, each having a different scan pattern. One is the calibration part and the other is the validation part.

Implement an appropriate layout, consistent with best practice for taking gas flow, blade moving direction, etc. into account. Ensure there is enough space between parts to accomplish the measurement procedure *before the parts are cut from the baseplate*. The parts need to be measured while they are fixed to the plate; hence, it is important to keep enough space between neighboring parts.

Support Structure

No support structures are required, the parts should be built on the baseplate directly.

Process Parameters

The parts should be built with process parameters that you are intending to use for building real components.

Scan Pattern for Calibration Part

Build one crossed walls part with the scan pattern as shown in Figure 3b:

- Scan pattern 1: bi-directional scan with 0 ° starting angle and 0 ° layer rotation angle, scan line is either 0 ° or 180 °
- There should be no extra scans such as contour scan, up-skin and down-skin, shrinkage factor, etc.

Scan Pattern for Validation Part

Build one crossed walls part with a different scan pattern that is directionally independent, such as the one shown in Figure 3c.

- Scan pattern 2: use the scan pattern that you are intending to use for building real components. (In this guide we use a rotating stripe scan pattern with a 57° starting angle and a 67° rotation angle.)
- There should be no extra scans such as contour scan, up-skin and down-skin, shrinkage factor, etc.

Taking Distortion Measurements

Measurements should be performed *before the parts are cut from the baseplate*. Several methods are available and 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 end surfaces of both walls making up the cross. You will use one point to calculate the SSF and/or ASCs. Use the overall dimension at either the Z location of interest, which is the center of the wall face at Z = 22 mm, or the dimension at the location of maximum distortion which should be near the location of interest. (Measurement locations should match with locations of data extraction from the simulations.) Record the value of the dimensions on the spreadsheet provided by ANSYS.

Laser Scanner

If using a laser scanner, points cloud or scanned STL file can be obtained. Measure distortion at the Z location of interest or a profile of the central line of every end wall surface.

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 Z height. Measure the dimension of each wall of the cross at the Z location of interest. This measurement technique is less accurate than the other methods and may result in bad distortion trends and SSF and ASCs. 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 use this modified geometry in your simulations.

Running the Simulations

In Additive Print, keep the following settings consistent for all simulations:

- Crossed walls part (*crossed_walls.stl*)
- Voxel size: 0.25 mm
- Material properties, either from an ANSYS-predefined material or your customized material
- Process parameters (needed for Thermal Strain simulations)
- No supports

Only default output options (On-plate stress/displacements) are needed. Additive Print Desktop allows you to prepare multiple simulations and queue them up to automatically run one after another. We recommend you use this feature to run the simulations. Or use Additive Print Cloud to run simulations concurrently.

Simulations in Calibration Step

Assumed strain:

- For linear elastic, start with the default SSF = 1
- For J2 plasticity, start with SSF = 2

Scan Pattern/Thermal Strain

- For linear elastic, start with the default SSF = 1
- For J2 plasticity, start with SSF = 2
- Start with default ASCs (1.5, 0.5, 1)
- Scan pattern 1 – use 0 ^{o} starting angle and 0 ^{o} layer rotation angle

Simulations in Validation Step

Assumed strain:

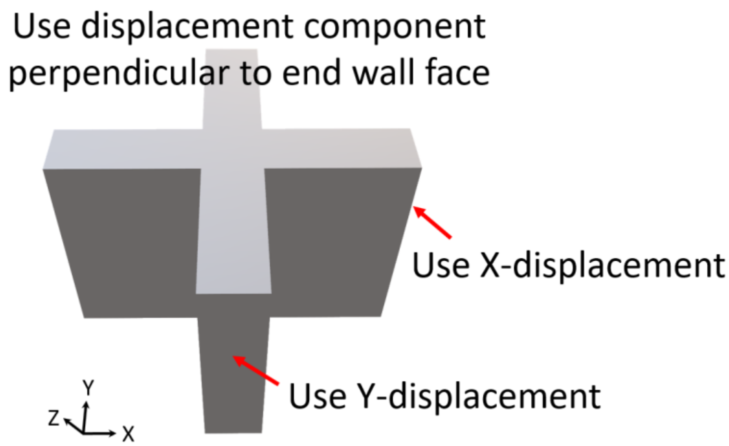
- For both linear elastic and J2 plasticity, start with the calibrated SSF

Scan Pattern/Thermal Strain

- For both linear elastic and J2 plasticity, start with the calibrated SSF
- Use the calibrated ASCs
- Scan pattern 2 – use a different scan pattern that is directionally independent (such as a rotating stripe scan pattern with a 57° starting angle and a 67° rotation angle)

Extracting Distortion Data

For each simulation, use the **On-plate stress/displacement** results to extract the directional component of displacement at the ends of the walls at the Z location of interest (center of wall face at Z = 22 mm). Always use the displacement component perpendicular to the end face of the wall, as shown in the following figure. Use either the ANSYS viewer in Additive Print to view the results (hover the mouse over the location of interest to get the displacement) or download the On-plate results file to view in another viewer application.



The data point coordinates at the locations of interest, as shown in Figure 3b, are:

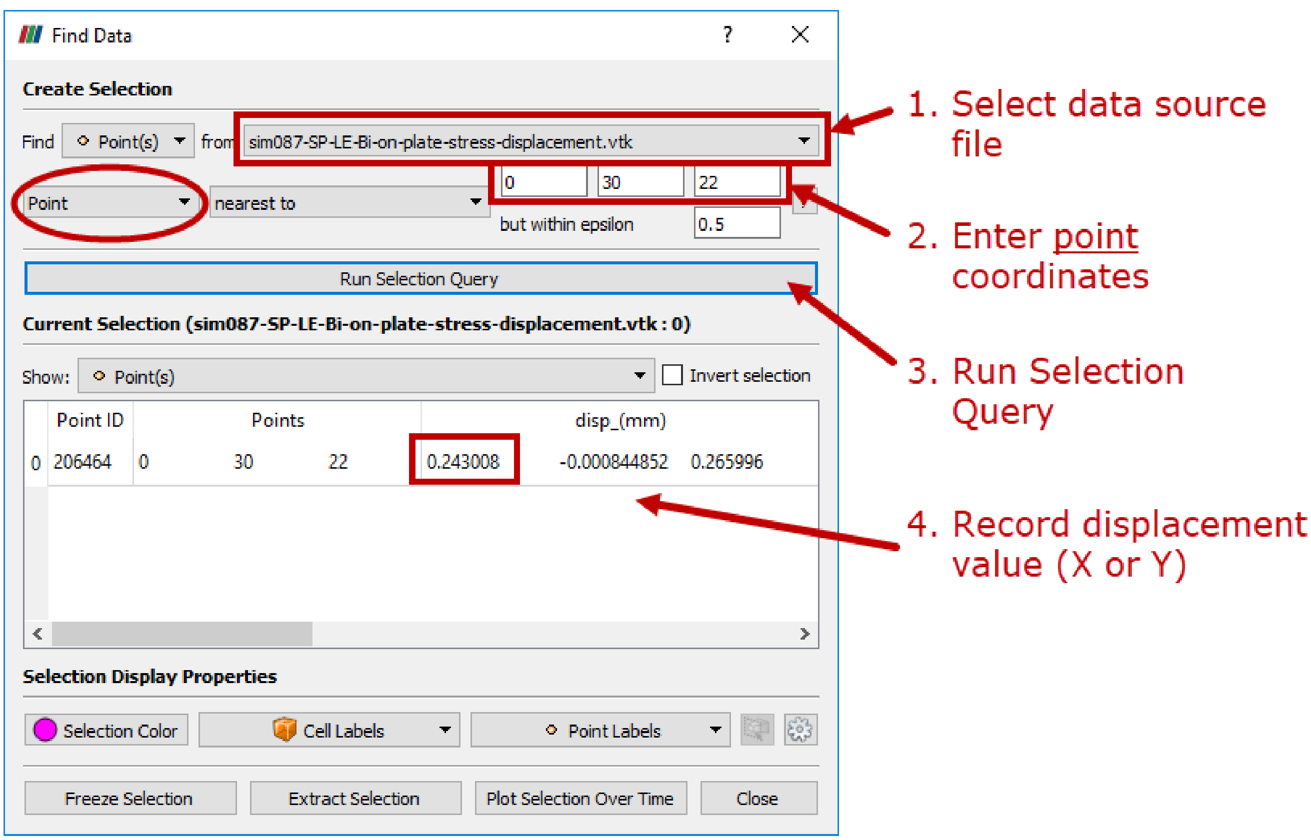
(0, 30, 22) or (60, 30, 22) Use X-displacement value

(30, 0, 22) or (30, 60, 22) Use Y-displacement value

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

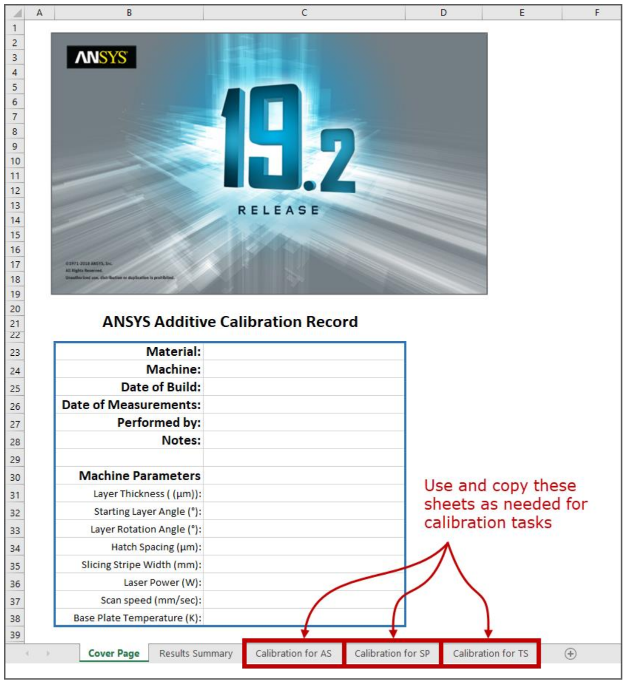
Open the appropriate file and make it active.

Edit > **Find Data…**

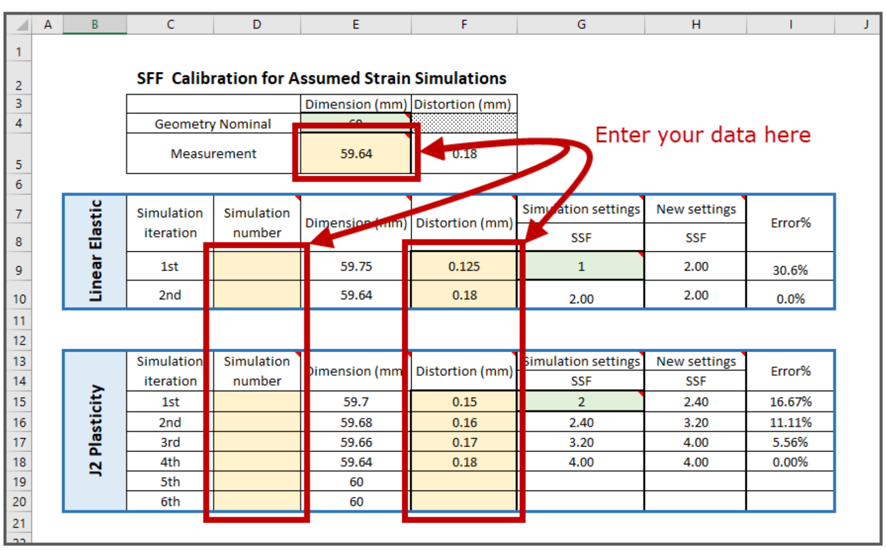


Using the Spreadsheet to Calculate SSF and ASCs

An easy-to-use, customized spreadsheet (.xls file) is available to calculate the SSF and ASCs. (The spreadsheet is available for download here.) Within the spreadsheet, you will see tabs at the bottom (Calibration for AS, Calibration for SP, and Calibration for TS) representing the three different simulation types.



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.



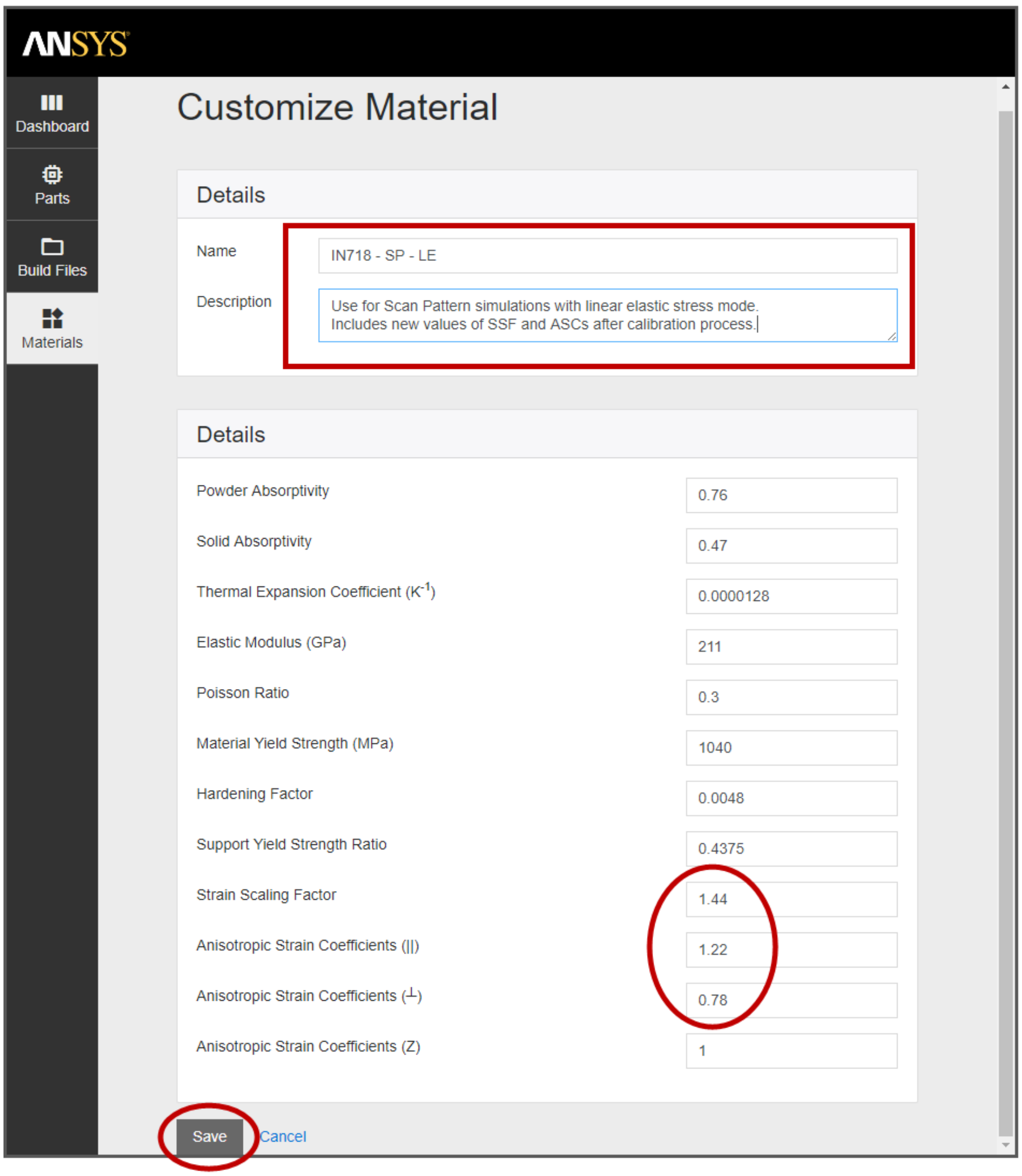
You will need to copy the validation sheet for other simulation types. The formulas are the same as in the Assumed Strain calibration step.

Saving Your Final Results as Custom Materials

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 Table 1 shown 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/validated) values. Then be sure to select the appropriate custom material when performing future simulations.



Appendix: Formulas for Calculating SSF and ASCs

The formulas used in the ANSYS-supplied spreadsheet are provided in this section as reference information.

Variables and Symbols

δe = Experimental distortion

δs = Simulation distortion

r = ratio

Subscripts:

$||$ = 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

Linear Elastic Stress Mode Calculations

Assumed Strain SSF:

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

Scan Pattern/Thermal Strain SSF:

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

Scan Pattern/Thermal Strain ASCs:

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

$$ASC \perp = 2 - ASC||$$

J2 Plasticity Stress Mode Calculations

Assumed Strain SSF:

Same initial SSF calculation as linear elastic stress mode but interpolates/extrapolates from there to find the correct settings.

$$SSF_1 = \frac{\delta e_0}{\delta s_0} * SSF_0$$

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

Scan Pattern/Thermal Strain SSF:

Similar to the assumed strain method, but now we average the perpendicular and parallel distortion measurements to get a single value. The first step uses the same method as linear elastic.

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

$$SSF_1 = \frac{avg(\delta e_0)}{avg(\delta s_0)} * SSF_0$$

$$SSF_{n+1} = \frac{\big(avg(\delta e) - avg(\delta s_{n-1})\big) * (SSF_n - SSF_{n-1})}{\big(avg(\delta s_n) - avg(\delta s_{n-1})\big)} + SSF_{n-1}$$

Scan Pattern/Thermal Strain ASCs:

Again, the first step uses the same method as linear elastic, which is followed up by interpolation to find the correct ASC values.

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

$$ASC||_1 = (2 - ASC||_0) * \left(\frac{\delta e_{||} * \delta s_{\perp 0}}{\delta e_{\perp} * \delta s_{||0}} - 1\right) + ASC||_0$$

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

$$ASC||_{n+1} = \frac{(r_e - r_{n-1}) * (ASC||_n - ASC||_{n-1})}{(r_n - r_{n-1})} + ASC||_{n-1}$$

$$ASC \perp = 2 - ASC||$$