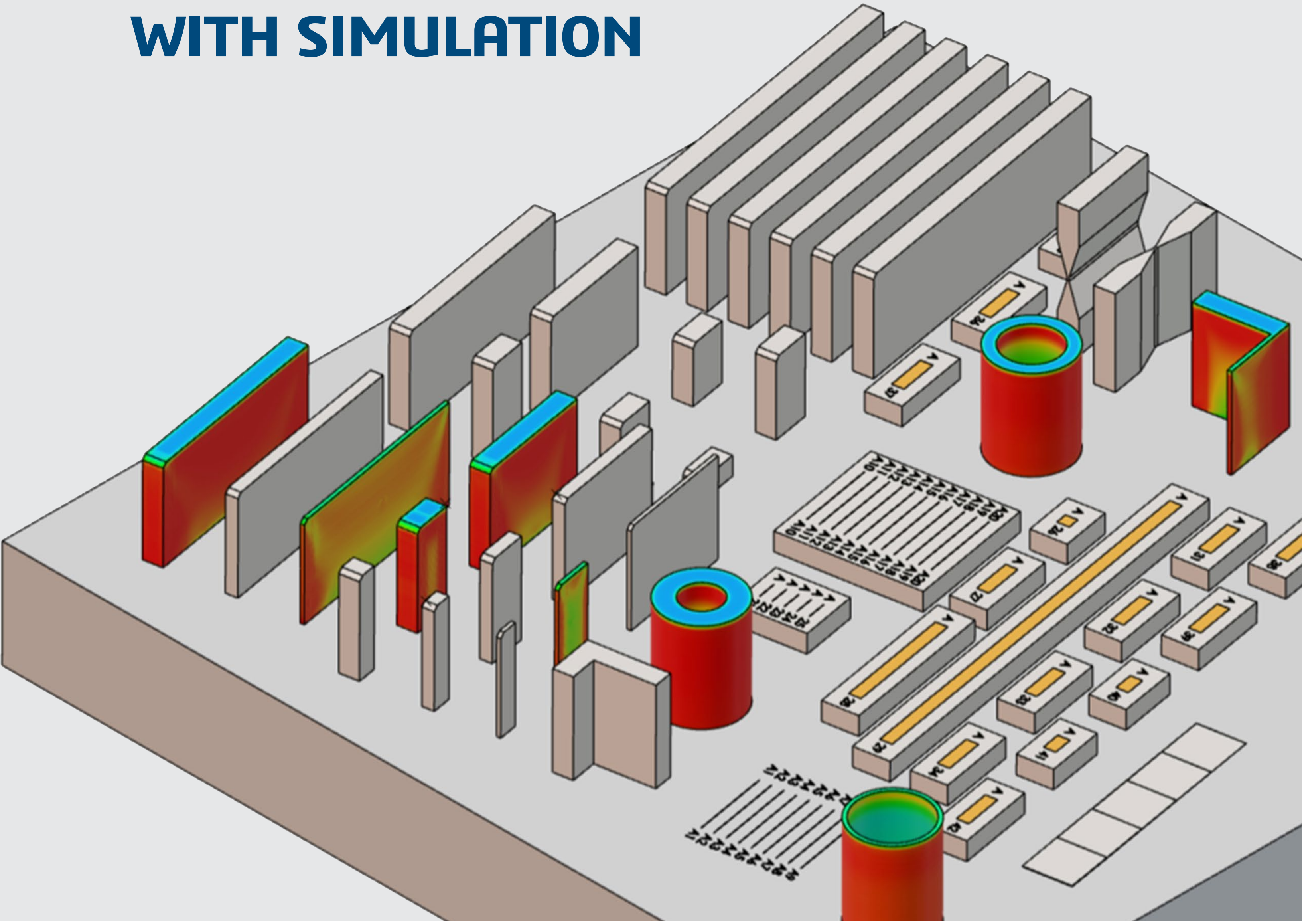
SIMULIA

3DEXPERIENCE

ACHIEVING REPEATABLE, HIGH-QUALITY ADDITIVE MANUFACTURING BUILDS WITH SIMULATION



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From designing one-off bespoke products to constructing components that would be impossible with traditional subtractive methods, additive manufacturing (AM) is providing value in numerous industrial applications. Scaling up AM processes however can be challenging, with repeatability and build quality issues being a major roadblock to adoption. Simulation offers a way to analyze AM processes and products before manufacturing as well as optimize for part strength.

Dassault Systèmes offers an end-to-end solution for additive manufacturing on the **3D**EXPERIENCE® platform. This whitepaper will focus on the role of simulation in that flow, and show how structural analysis can accurately predict residual strains in 3D printed parts. The solution demonstrated in this paper is experimentally verified and came in first place in the Air Force Research Laboratory (AFRL) "Macro-scale Process-to-Structure Predictions" challenge.

INTRODUCTION

Understanding the properties of 3D printed parts requires a detailed understanding of the process used to construct those parts. In general, heat is applied to fuse deposited materials during the manufacturing process. As the material cools and solidifies, it contracts and thermal strains accumulate within the part. These strains can lead to problems such as deformation and brittleness, and in some cases can cause the build to fail entirely.

The residual strains inside the build part are not only a function of the geometry of the part itself, but are also dependent on the thermal conditions of the base material, build plate and build chamber, the speed and scan path of the print head, and the order of printed features in relation to one another. To properly capture all of these complexities for a 3D printed part requires accurate simulation of the entire printing process.

To determine the best practices for AM simulation, the Air Force Research Laboratory organized a series of challenges. The first challenge, "Macro-scale Process-to-Structure Predictions", gave participants the build CAD data, numerous process details, and calibration measurements for a test piece which would be constructed using powder bed additive manufacturing in Inconel 625. The challenge task was to calculate the strain in several parts of the manufactured build using simulation.

DASSAULT SYSTEMES AM SIMULATION SOLUTION

The **3D**EXPERIENCE platform offers an end-to-end workflow for AM from design to production. Different experts in an organization including designers, machine process specialists and analysts can collaborate, both on premise and in the cloud.

The solution covers all the different steps of developing an AM process. This includes designing the part, optimizing its topology, planning the build process, and calculating the strain and deformation of the finished part. This whitepaper focuses on that last step—analysing the final part once it has been designed and a build process has been chosen.

Since the build geometry was provided by AFRL, the first step was to import the CAD geometry. 3D data formats, such as STL commonly used in 3D printing, can be imported into the simulation environment and used to generate a finite element (FE) mesh. The CATIA Digitized Shape Preparation app repairs and validates the STL mesh and produces a simulation-ready model.

The second step is slicing the geometry and generating the laser scan path of the build. For this, the DELMIA Powder Bed Fabrication app was used on the provided CAD geometry, specifying all the parameters of the scan strategy provided in the challenge problem statement.

Accurate prediction of the strain in the build parts required a precise consideration of total thermal energy and input heat flux per layer. As a result, all components in the build setup should be considered, even if they are not included in the simulation. This guarantees that the total printing time of each layer (scanning and recoating) used in the simulation was as close as possible to the actual printing process. For example, in the AFRL model, the print time for upper layers was shorter, as fewer taller parts are included. The lower layers had longer print times due to the numerous shorter parts, and this difference affected the resulting thermal pattern. The DELMIA Powder Bed Fabrication app accurately recreated the scan path for the physical build, allowing the ability to capture this effect.

The SIMULIA Additive Manufacturing Scenario app then sets up and runs a thermomechanical-analysis of the AM build process. This app provides a computationally efficient and a highly scalable framework for simulating AM processes.

The framework allows activation of elements in a progressive fashion during the analysis, and a continuously evolving free external surface reflects the present shape of the part at a given time during the build process, in order to model radiative and convective heat transfer. A moving heat flux simulates the laser heat source with its energy uniformly distributed over a laser spot-sized region. The toolpath-mesh intersection module computes the element activation sequence, the heat energy input, and the evolving free external surface by intersecting the toolpaths of the laser and the recoater and the FE mesh in a geometric sense.

The thermal and mechanical simulations are coupled together automatically by the app. First, a transient heat transfer analysis is done, which takes into account the material deposition sequence for element activation and the scanning path of the laser beam for heating. The temperature field calculated by the thermal analysis is then used to drive a static structural analysis, which computes the residual strain inside the part.

EXPERIMENTAL VERIFICATION

The AFRL challenge offers an opportunity to demonstrate the physical validity of simulation results from the SIMULIA Additive Manufacturing Scenario app. Accuracy is key for leveraging simulation capabilities to produce high-quality AM parts.

Figure 1 shows strains in the longitudinal (a and b) and the printing directions (c and d) on the 1 mm leg of the L shaped part. The dotted red lines in figure 1(b) and (c) are the simulated microstrains, the black lines are the experimental values and the grey lines show an interval of 2σ (500 microstrain) around the experimental values. On a large portion of the part, the simulated strains are within the 2σ interval of the experimentally measured strains.

Figure 2 depicts strains in the radial and the printing directions on a long section (x-z plane) of the 5 mm cylindrical part. On a large portion of the part, the simulated radial strains are within the 2σ interval of the experimentally measured strain. Whereas the strains in the printing direction were within the 3σ interval of the experimentally measured strain on almost the enter part. The dotted red lines in figure 2 (b) and (c) are the strain from simulation, the black lines are from the experiment and the grey lines show an interval of 2σ around the experimental curve. The variation of strains along the printing direction (x) at given heights (z) from simulation qualitatively agrees with those found experimentally.

CONCLUSION

An accurate understanding of the properties of 3D printed parts requires a precise analysis of the additive manufacturing process. The SIMULIA Additive Manufacturing Scenario app replicates the print process step-by-step to accurately calculate how thermal stresses develop as the part cools. This means that build quality can be assessed before committing to physical printing and the effect of design and process changes can be quickly analyzed. The accuracy of the SIMULIA simulation solution has been experimentally verified, and the solution won first prize in the Air Force Research Laboratory (AFRL) "Macro-scale Process-to-Structure Predictions" challenge. The simulation app forms part of the end-to-end additive manufacturing flow on the Dassault Systèmes **3D**EXPERIENCE platform with tools for designing, optimizing, planning and analyzing 3D printed parts and processes, which speeds up development and enables innovation.

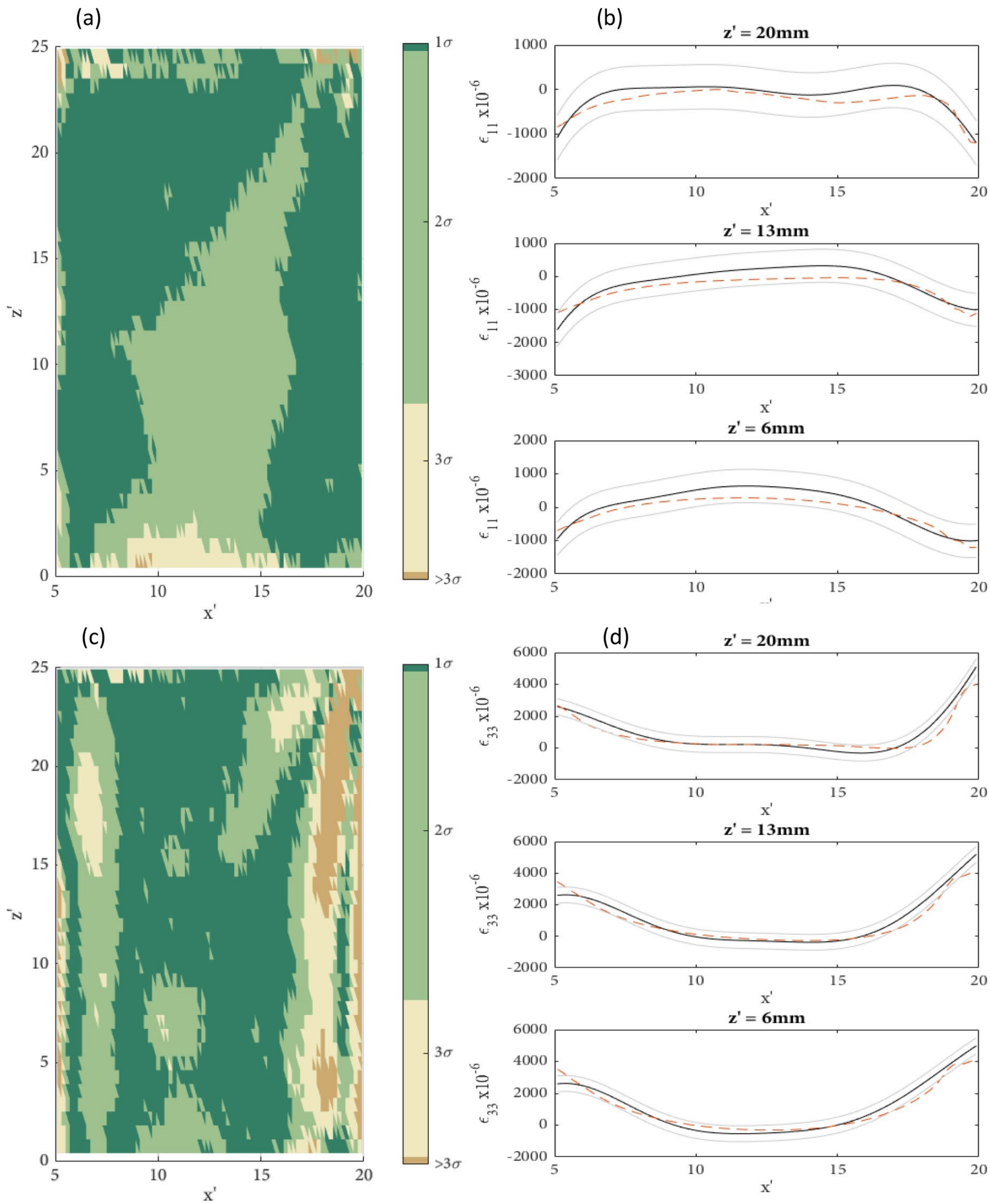


Figure 1: Elastic strain in the longitudinal and printing directions of the thinner 1 mm leg of the L shaped part. Figures (a) and (c) shows the difference between the experimentally measured strain and the strains from simulation in terms of the standard deviation σ of the measure strains. Lengths x' and z' are in mm. The dotted red lines in (b) and (c) are the strain from simulation, the black lines are from experiment and the grey lines show interval of 2σ around the experimental curve.

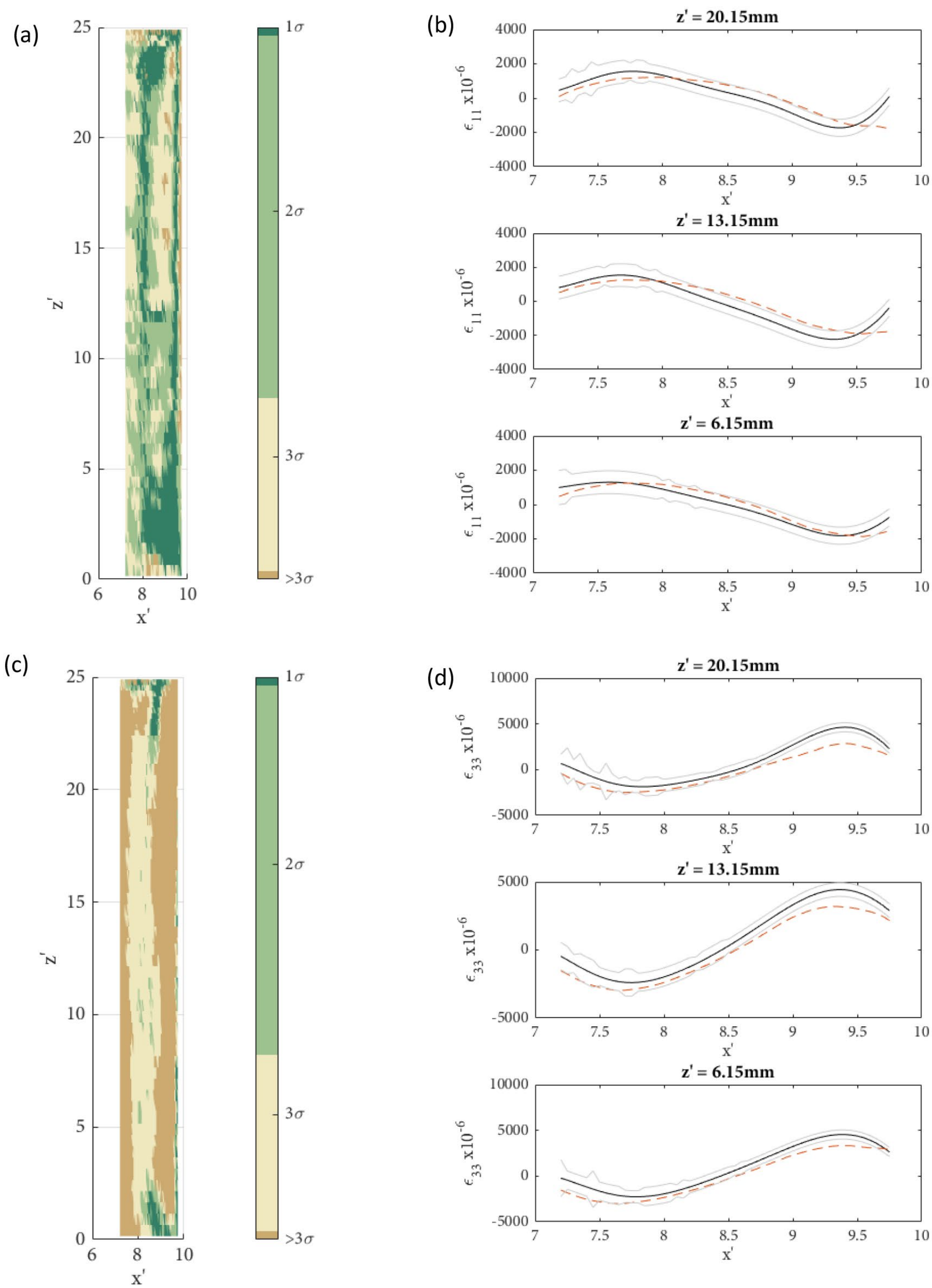
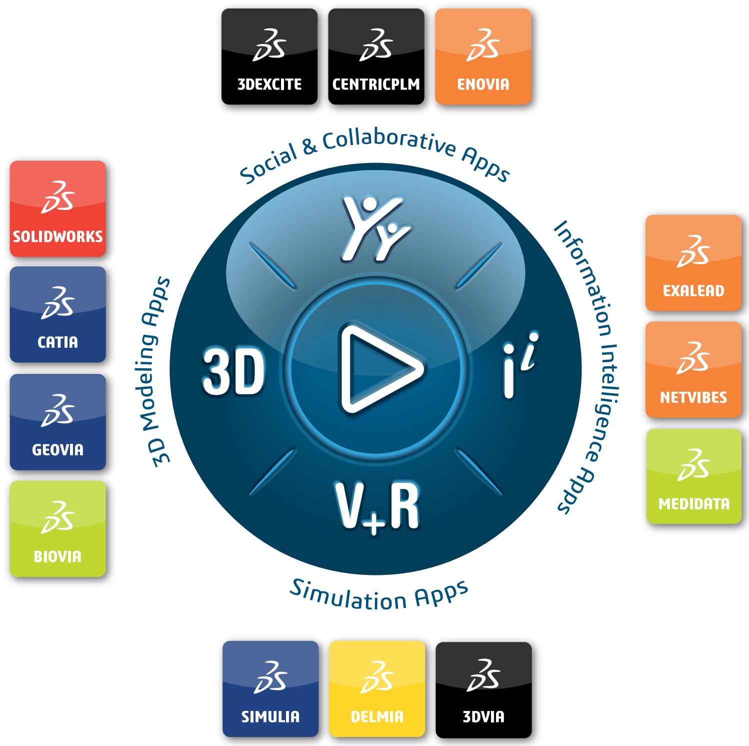


Figure 2: Elastic strains in the radial and printing directions of the 5 mm cylindrical part. Figures (a) and (c) shows the difference between the experimentally measured strain and the strains from simulation in terms of the standard deviation σ of the measure strains. Lengths x' and z' are in mm. The dotted red lines in (b) and (c) are the strain from simulation, the black lines are from experiment and the grey lines show interval of 2σ around the experimental curve.



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