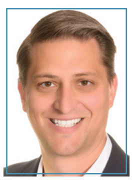
Simulating the effects of warpage in an additively-manufactured composite layup tool



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Additive manufacturing (AM), by definition opposed to subtractive methods, regroups a number of manufacturing processes allowing the creation of parts from 3D numerical CAD models by building up the components in layers by depositing material, hence not requiring specific mould tooling design. This way, low-volume, complex parts can be produced at fixed cost in less time. This article focuses on the development and validation of additive manufacturing process simulation.

As lightweighting becomes a top design priority for the automotive and aerospace markets, the capability to reduce the number of parts by directly manufacturing an assembly is a promising source of gain. Lattice structures are also increasingly interesting industry players seeking the optimum mix of mechanical performance and low density. Such design opportunities offered by AM technologies can lead to weight reductions of several tens of percent.

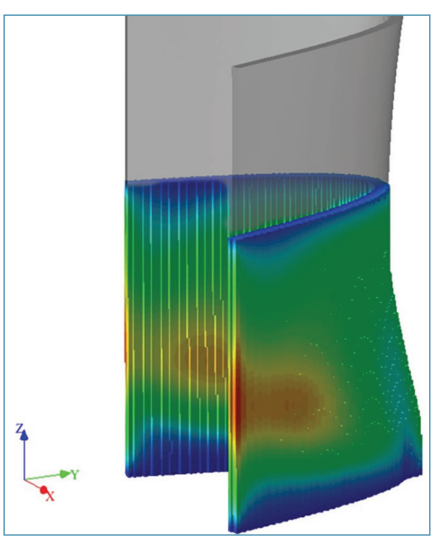

Fig 1: Warpage simulation of a composite layup tool during FDM process

Additive manufacturing has been rapidly developing over the last few years, notably with plastics and reinforced plastics applications. To ensure the competitiveness of the additive manufacturing process, certain requirements must be met such as the replicability of process and part performance and addressing the needs of high-performance industrial applications. The inherent complexity of additive manufacturing calls for simulation tools to offer high-performance designs and a greater dimensional accuracy of 3D-printed parts.

For nearly 30 years, Stratasys has been a defining force and dominant player in additive manufacturing – notably inventing the Fused Deposition Modelling (FDM®) technology. The company's solutions provide customers with unmatched design freedom and manufacturing flexibility, reducing time-to-market and lowering development and manufacturing costs.

FDM is becoming the technology of choice for the rapid production of high-temperature (>177°C), low-volume composite lay-up and repair tools, as well as for moderate-temperature (<163°C) production sacrificial tooling. Relative to traditional tooling materials and methods, FDM offers significant advantages in terms of lead time, tool cost and simplification of tool design, fabrication and use, while enabling increased functionality and geometric complexity.

Challenges

To unlock the full value additive manufacturing has to offer, simulation tools are needed to predict and mitigate part warpage, and to determine

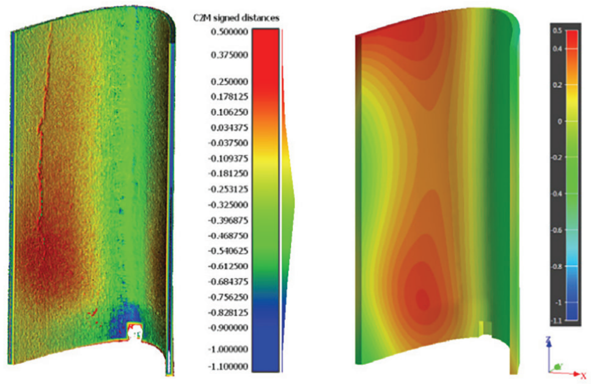

Fig. 2: Comparison between measured warpage on a physically-printed part (RMS signed distance, left) and Digimat-AM warpage prediction (X displacements, right)

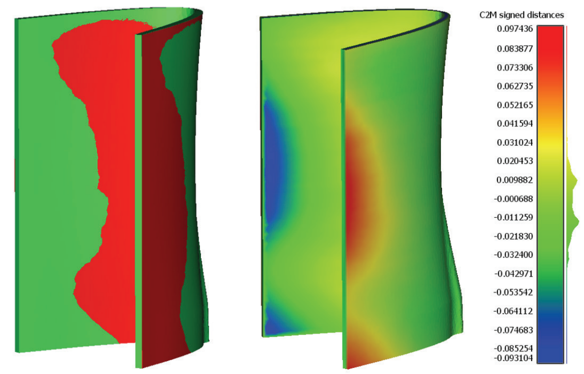

Fig. 4: Warpage prediction after geometry compensation in Digimat-AM. Left: superposition of the as-printed (red) and as-designed (green) parts; right: RMS signed distance, maximum deviation is less than 0.1 mm

the impact of design decisions on the manufacturing process before the part is printed.

The development of this process simulation is facing several challenges:

- Complex thermomechanical loadings occur during the layer-by-layer deposition of the material and the successive cooling of the part;
- Additive manufacturing is a true multi-scale challenge: the position of bead deposition creates specific microstructures based on the printing toolpath pattern, which drives the macroscopic mechanical behaviour – typically inducing anisotropy;
- The thermal history of the material deposition generates differential shrinkage between adjacent beads or layers that affects the end tolerances of the part.

Overall, modelling the printing process requires taking into account the material state evolution to model the stress build-up as well as the stress relaxation over time. Numerical predictions of warpage need to account for the process parameters, the material characteristics and the printing strategy (part orientation, toolpath, supports, etc.).

A multi-scale approach

Stratasys is working with e-Xstream to create FDM process simulation via a multi-scale approach as a function of the process setup and material choice. This approach includes the following steps:

- Solving a fully-coupled thermomechanical problem of the deposition process to identify the warpage behaviour of the printed material accounting for thermal exchanges inside the printer build (conduction, convection and radiation);
- Loading the toolpath issued from the manufacturing processing software and extracting information about the deposition sequence;
- Modelling, via micromechanics, the heterogeneous material microstructure as a function of the toolpath (e.g., porosity volume fraction and orientation);
- Predicting the resulting warpage induced by the printing process;
- Iterating the design and optimizing the manufacturing process parameters to minimize warpage.

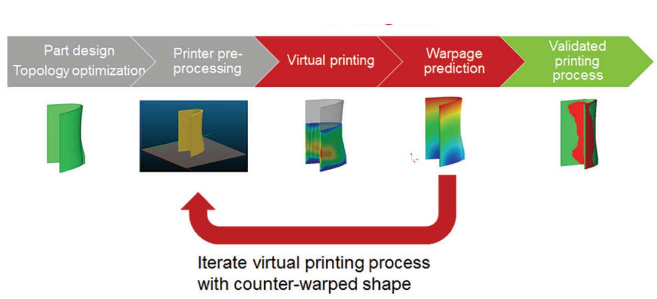

Fig. 3: Digimat-AM simulation approach for optimal printing

Results and benefits

As a direct result of the collaboration between Stratasys and e-Xstream Engineering, the main objective of the process simulation is to print right the first time. Designs and process parameters can be investigated through the numerical simulation while the printed part fidelity can be controlled before the first physical printing. More importantly, the simulation workflow enables to minimize warpage in only two steps using a predeformed geometry. Working with Digimat-AM, Stratasys engineers are thus able to save time and material by anticipating printing issues with simulation (e.g., evaluate the impact of the printing direction and location on the results).

Virtual engineering is the solution to optimize the manufacturing process because it enables the user to explore the process sensitivity to manufacturing parameters at virtually zero marginal cost. The process simulation experience in Digimat-AM is accessible to non FEA experts thanks to its easy, efficient and user-friendly GUI designed to follow the physical printing workflow.

Results correlation to test data

The warpage prediction was compared to 3D-scan measurements of a physically-printed composite tool. Given the different mod¬elling assumptions, the comparison shows a good general correlation with a similar deformation pattern and amplitude. The warpage compensation procedure significantly decreases the maximum deviation between the reference geometry and the as-printed part (from 0.5 mm to less than 0.1 mm). ◻

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