3D Printing

Predicting Markforged additive manufacturing performance with simulation software

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Markforged provides unique additive manufacturing (AM) composite materials consisting of a base engineering plastic, typically Onyx, and continuous fiber strands that compete with the strength of metals. When designing with multi-material composites, how do you make sure that your design satisfies the parts technical requirements, or that you're not overdesigning?

Markforged & Hexagon | MSC Software have partnered to solve this problem. Everyone in the AM Community will agree AM final part properties are highly dependent on the additive process, which constrains high-end industries, such as aerospace, to certify an ensemble material-printer-process-part. For both metals and composites, there is a need to establish the link between material properties and final part mechanical behaviour. For metals, part mechanical behaviour is impacted by building direction, surface roughness, and porosity. For continuous fiber reinforced composites, the tool pathing that lays fiber orientation is the largest factor that drives mechanical behaviour.

This is exactly what we love to do at Hexagon | e-Xstream Engineering: go back to the manufacturing to understand how the material was processed (defining its microstructure) and to accurately predict the material behaviour and the design performance with an approach called Integrated Computational Materials Engineering (ICME). As the leader in composite material modelling, we started developing our material modelling platform Digimat 16 years ago. As an example, our technology enables our customers to perform an injection molding simulation, deduce the fibers orientation everywhere in the part, and run a coupled finite element analysis (FEA) simulation that will use this as-manufactured material microstructure to derive the right mechanical behaviour. With the same philosophy, this successful workflow is now expanded to AM. This partnership owes its birth to Danfoss, a global industry leader that provides hydraulic and electronic solutions for mobile equipment. Danfoss realized that the same validation tools used in traditional manufacturing processes were needed for AM and proposed to us creating these tools in partnership with Markforged. They also came with a sample part to be evaluated and tested. This part, previously machined from Aluminium, is a bracket used to lift housing castings along in the assembly process. It benefits from AM as:

- It allowed the team to make unique geometry that matched the shape of the housing easier than we could with traditional manufacturing; and
- It enabled quick iterations and configurations to find a design that holds the pump securely and does not allow lifting in any other orientation (poke-yoke design)

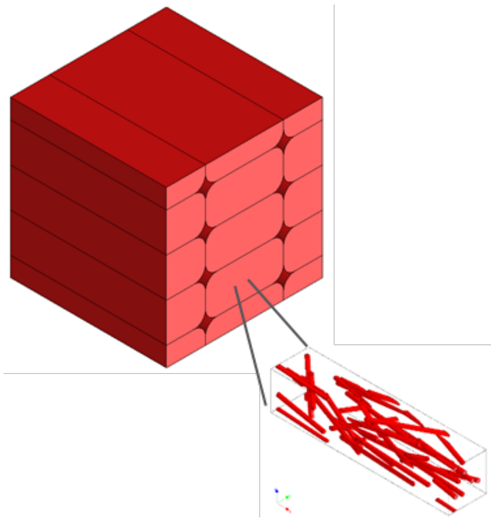
- Previous (similar) fixtures have been machined from Aluminium.

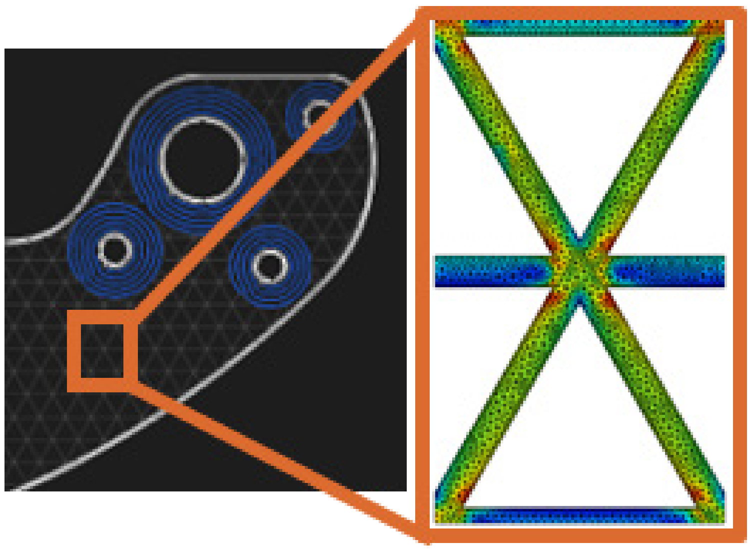
Modelling Markforged composite materials is a true challenge as a part will typically be made of:

- an Onyx shell (a few dense layers/beads that define the part outer surface)
- a lightweight infill (e.g., a triangular pattern that partially fills the interior to save time and material)
- two levels of reinforcements (chopped carbon fibers within the Onyx base material and carbon/glass/Kevlar continuous fibers)

This requires a multiscale modelling approach to consider the effects at the microscale level on the effective material properties.

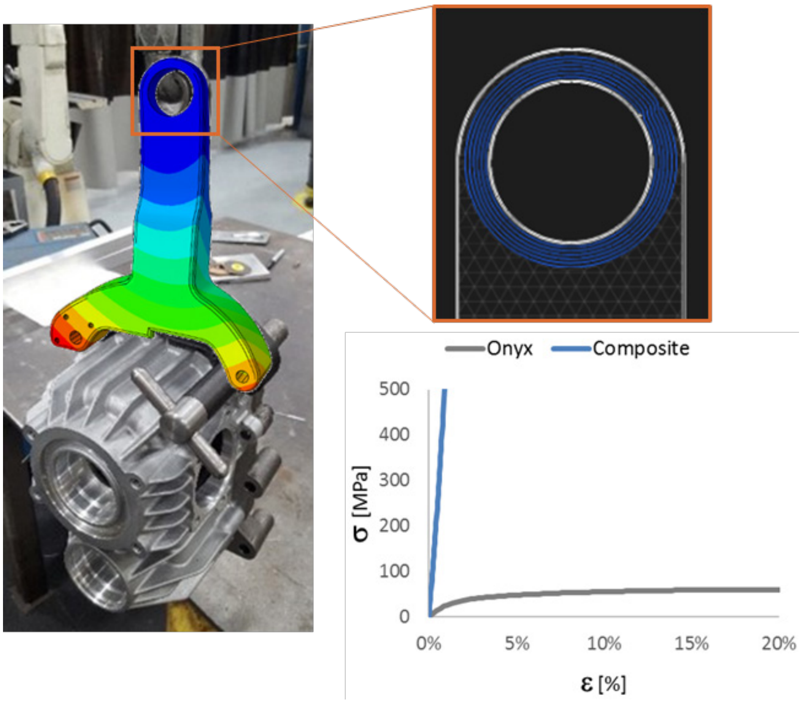
To tackle the challenge offered by Danfoss, a finite element (FE) mesh of the part was built and the load and corresponding boundary conditions were defined. We then defined an experimental test with Markforged on the Onyx and Composite materials. The analysis of the mechanical test data serves to determine how the material precisely behaves--that is, how anisotropic it is in terms of stiffness and strength due to the toolpath direction and the material's microstructure. Upon post-processing of the experimental data, two Digimat material models have been calibrated together with a failure model that captures the toolpath dependent behaviour of the material (for both Onyx and





Composite). Finally, the triangular infill has been virtually tested in Digimat by preparing and solving a separate FEA on a representative unit cell of the infill pattern. Once the material had been characterized, we needed a second key ingredient for the simulation: the manufacturing data – in this case, the toolpath. Since it used proprietary information from Eiger, a dedicated interface was developed to export the manufacturing data to Digimat. It was then read, analysed and converted into a format suitable for the simulation and mapped onto the structural FE mesh. At this stage, the coupled Digimat-FEA simulation was ready to run.

Danfoss' lifting tool has been physically tested to failure on an Instron machine. The simulation results of the Onyx-only part are in good agreement with the experiments: the failure location (close to the hole where the loading is applied) is accurately predicted, and the maximum force that can be applied underestimates the physical test by 25%.



Of course, further improvements will be investigated to enhance the simulation accuracy. For today, let's imagine we did not get the physical test (and you don't want to test each part): the simulation tells you that the part actually sustains four times the technical requirement (that embeds itself a safety factor of 5), all that without the CF! Needless to say, there is a large potential to cut down mass and cost.

This story is just the beginning of a very exciting journey, as these simulation capabilities will be integrated in the Digimat 2020.0 platform. Users will also benefit from process simulation to better understand how to master the FFF printing process. In the medium term, we can foresee a lot of synergies between Markforged and MSC, as Hexagon is a global leader in sensors and metrology hardware and software, paving the way for a strong digital continuity approach.