

# simulating **REALITY**

MSC Software Magazine | Volume VII - Summer 2017 Issue

NEW  
DEVELOPMENTS  
IN SIMULATION  
**FOR PLASTICS  
& METALS**



# **ADDITIVE MANUFACTURING**



# 2017 ADDITIVE MANUFACTURING WEBINARS & EVENTS

## WEBINARS



For upcoming webinars  
on AM please visit:

[www.mscsoftware.com](http://www.mscsoftware.com)

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## LIVE EVENTS

- Digimat-FE for Material Engineering & Effects of Defects  
Lunch & Learn - August 18<sup>th</sup>, 2017  
Troy, MI - [www.mscsoftware.com/event4](http://www.mscsoftware.com/event4)
- CAMX - September 11-14<sup>th</sup>, 2017  
Orlando, FL - [www.thecamx.org](http://www.thecamx.org)
- Global Digimat Users' Conference 2017 - October 4-6<sup>th</sup>, 2017  
Berlin, Germany - [www.mscsoftware.com/event7](http://www.mscsoftware.com/event7)
- Additive Manufacturing Conference - October 10-12<sup>th</sup>, 2017  
Knoxville, TN - [www.additiveconference.com](http://www.additiveconference.com)
- Formnext - Nov 14-17<sup>th</sup>, 2017  
Frankfurt, Germany - [www.mscsoftware.com/event8](http://www.mscsoftware.com/event8)
- FABTECH 2017 - November 6-9<sup>th</sup>, 2017  
Chicago, IL - [www.mscsoftware.com/event9](http://www.mscsoftware.com/event9)
- Rapid + TCT - April 23-26<sup>th</sup>, 2018  
Fort Worth, TX - [www.rapid3devent.com](http://www.rapid3devent.com)

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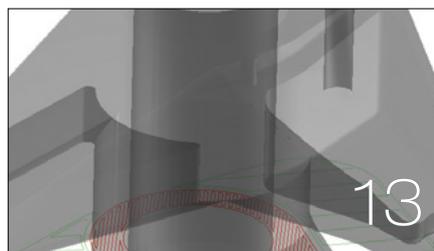
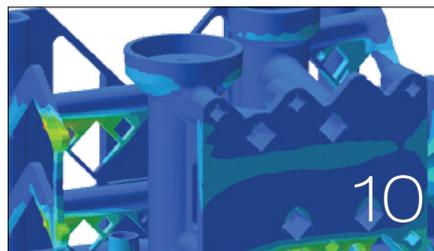
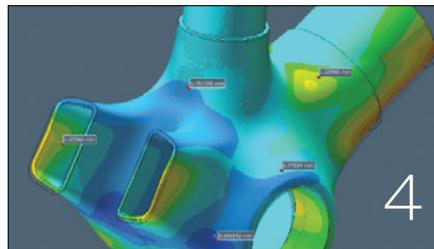
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# Turning Yesterday's Science Fiction into Today's Reality

by Dr. Masha V. Petrova, Director of Global Marketing, MSC Software

Growing up in the former USSR, one of my favorite things to do as a child was to read science fiction books. A novel that I read over and over again was written in 1965 and described the exciting life of Alisa Seleznyonva, a teenage girl from "the future". Alisa's father was an "astrozoologist", who studied animals from other planets. Alisa frequently got herself into trouble by sneaking into spaceships that were departing to other galaxies and bringing home random space creatures and humanoid robots.

While today, we don't have to worry about our children cutting school to sneak off to some distant planet, at least one of the futuristic concepts present in Alisa's world is coming into reality before our very eyes. In one of the chapters, the book describes Alisa watching a new skyscraper being built in her metropolitan city. The building was literally "sprayed" onto itself from a hose using futuristic ultra-strong, ultra-light, & ultra-durable foam. This allowed the builders to create any shape they could imagine for a building that would house thousands of people in just a matter of days. I did not know it at the time, but the Russian author writing this story in the mid-60s behind the iron curtain, was describing a process that has evolved before our very eyes today – Additive Manufacturing (AM) a.k.a 3D printing.

With the promise of endless possibilities for new structures, designs, and materials, Additive Manufacturing is currently in the uber-hyped mode. Not a week goes by without a new AM technology emerging or a new AM deal signed. Last year, the U.S. Air Force awarded \$6 million to Aerojet Rocketdyne to develop standards for rocket parts made by AM. SpaceX received \$33.6 million to develop the Raptor rocket propulsion system to be manufactured primarily using AM. General Electric announced that it would spend \$1.4 billion to acquire two European 3D printing companies, and the list goes on.

As far as the futuristic "foam" described in the book, Additive Manufacturing is opening the door for the creation of all kinds of new materials. In powder bed fusion processes, for example, simply mixing two different metal powders together in varying proportions before feeding the powder into the printer, allows manufacturers to create their very own customized alloys. With plastics and composites this process can arguably be even more diverse.

Yet, we are still far off from AM becoming the next industrial revolution. MSC's CEO, Dominic Gallelo, described very well why this is the case in his piece [Additive Manufacturing - From Trial and Error to a True Revolution](#). As the investment in AM increases, so do the risks. Failures, cracks, & high distortion in unexpected areas might be part of the learning process, but are proving to be very costly.

Thus, we have dedicated this year's Simulating Reality to AM. Highlighted in this issue are MSC's solutions for both Plastic and Metal AM processes to allow you, your teams, and your companies to get 3D printed parts first time right. If you're looking for state-of-the-art solutions that will be essential in transitioning AM out of science fiction stories, through the "maker movement", and rapid prototyping, and finally into a full-fledged manufacturing process – read on.

And who knows, we might just see buildings being 3D printed out of ultra-durable foam in our lifetimes.

Happy reading,

Masha V. Petrova  
Director of Global Marketing

simulating  
**REALITY**



## Editor-in-Chief

[Dr. Masha V. Petrova](#)

[masha.petrova@mscsoftware.com](mailto:masha.petrova@mscsoftware.com)



## Senior Editor

[Nicole Drake](#)

[nicole.drake@mscsoftware.com](mailto:nicole.drake@mscsoftware.com)



## Senior Graphic Designer

[Marina Carpenter](#)

[marina.carpenter@mscsoftware.com](mailto:marina.carpenter@mscsoftware.com)



## Graphic Designer

[Elizabeth Yeh](#)

[elizabeth.yeh@mscsoftware.com](mailto:elizabeth.yeh@mscsoftware.com)

**MSC Software**

## MSC Software Corporation

4675 MacArthur Court, Suite 900

Newport Beach, CA 92660

714.540.8900

[www.mscsoftware.com](http://www.mscsoftware.com)

# Quick Simulation Pays Dividends

Able to rapidly assess part buildability and performance, simulation software is an ideal addition to any AM user's toolkit.



by [LOUIS KREN](#)  
Senior Editor,  
[3D Metal  
Printing Magazine](#)

For many, additive manufacturing (AM) is envisioned as a process that can simply print a part. From CAD to STL to the machine and, voila, here's your part, right and proper and good to go for you and your customer alike. There's an expectation that the odd-looking part, created on a computer, can simply be replicated in an AM machine. Perhaps it's unfortunate that the term 3D printing has taken hold. It implies a process similar to that of a paper copy machine. But, as those in our industry find on a daily basis, nothing is further from the truth.

Then, how can we protect ourselves from frustrating trial and error and wasted machine time, not to mention wasted labor and material? This is where simulation shines.

## Captures Distortion and Residual Stresses

In a recent [webinar](#), [Arjaan Buijk](#), MSC Software's business development manager for [Simufact](#), simulation software for metal manufacturing process chains including AM, identifies three challenges where 3D-printing simulation can assist:

- 1. Distortion.** During the build, parts tend to bend out of tolerance.
- 2. Residual stresses.** Stresses during build can lead to part failure, cracking and other unfortunate events, or support failure.
- 3. Quality.** When 3D printing, material is created as the part is created. For an ideal, high-quality part, the material must meet porosity, microstructure and other requirements.

Proper simulation, performed at the ideal point in the design-build timeline, can optimize the metal-AM process—providing accurate results while reducing costs and time to market.

In the webinar, "Additive Manufacturing Process Simulation for "First Time Right," Buijk touts the advantages of simulation as part of a test-based approach to 3D metal printing.

"When something goes wrong as the part is built, the team must go back, perhaps redoing the initial design and performing all pre-processing again," he says.

To minimize that costly and time-consuming situation, Buijk stresses that simulations occur "left of print." That means prior to the printing process.

"Results of simulation can affect topology optimization," he explains, "so a feedback loop prior to printing can optimize materials, processes and structure, which hopefully gives you a first-time-right build and ideal part performance."

## Macro-Scale Simulation Offers Quick, Accurate Read

Simulation for AM can occur at three levels, according to Buijk: micro, meso and macro.

*Continued...>>*

Micro simulation is highly detailed and delves deeply into microstructure. Due to cost and time, this process is best performed on small parts or small part sections.

“For full build or for larger parts, meso- or microscale simulation is a better approach,” he says. These simulation approaches are simplified and provide enough detail to address process and build concerns and greatly improve the chances of a first-time-right build.

Macro-scale simulation, exploring a build in voxels, “is extremely fast, featuring a calibration test to determine inherent strain parameters,” Buijk offers. “Accurate part-distortion and residual-stress results can be gained with such simulation.”

To validate the Simufact macro-scale simulation process for AM, MSC worked closely with the Fraunhofer Institute in Germany, reports Buijk. The team used simulation to validate builds on a variety of metal structures.

One case examined an aluminum aircraft bracket (see image below). A couple years ago, when the testing took place, simulation ran about 20 min. Today, Buijk reports, it can be done in 5-10 min.

“The simulation captured distortion very accurately,” he says, enabling the team to optimize design prior to build and ultimately delivering an acceptable part.

Another case: a thin-walled titanium part for a bike frame (see image).

“Thin-walled structures produced using AM tend to distort,” Buijk explains. “Our objective here was to see how well simulation with inherent strain captures distortions.”

Simulation results captured distortion of tube diameters and failure of support structure.

In both cases, the simulation was validated.

## Build Parts with Confidence

“Once you have calibrated the AM machine via inherent-strain data and have that strain data in a library, you can begin building parts with confidence,” Buijk says. “Robust macro-scale simulation allows users to explore the influence of parameters and materials, cutting direction, and support removal. Users can test build orientations, vertical or horizontal, and examine differing support configurations. Then the process chain can be addressed, with such simulation enabling study of the sequence of steps taken when building the part.”

Importantly, simulation can extend beyond the actual build itself, reports Buijk. For example, the process can address detachment from baseplate, influences of heat treatments to remove residual stresses and mechanical influence of hot isostatic pressing.

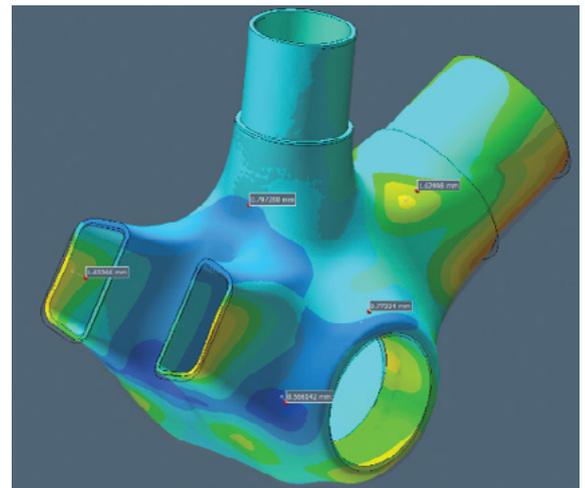
Given the expense of material and machine time, robust simulation can reduce process complexity and pay off in the bottom line.

Consider that various factors influencing the AM process, including a variety of production methods and their special physics, a variety of 3D-printing machines and their machine-specific influence on the production process, and differing metal powder quality. On top of that, AM involves a large number of machine input parameters (as many as 200), all having an impact on the behavior of the final parts.

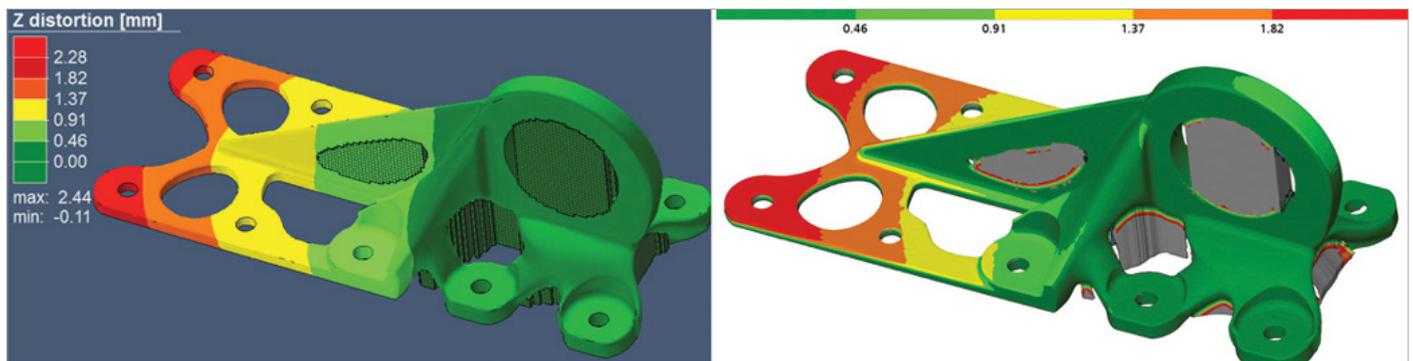
Simulation can whittle all of these variables down, streamlining the design-build process. With effective simulation at users’ disposal,

// **With effective simulation at users’ disposal, the learning process is shortened and more part variations can be explored prior to production.**

the learning process is shortened and more part variations can be explored prior to production. Assisting with end goals such as quickened time to market, increased machine/manpower availability and reduced material and energy consumption, simulation seems to be an effective addition to any AM user’s toolkit. ♦



Bike frame - Simulating a thin-walled titanium part for a bike frame, reveals distortions, a relatively common occurrence in AM-produced thin-walled parts.



Aircraft bracket - A quick simulation of an aluminum aircraft bracket identifies areas of distortion

# New Developments in Simulation for AM



by **Michael Wohlmuth**  
CEO, Simufact

**Dr. Hendrik Schafstall**  
CTO, Simufact

**Arjaan Buijk**  
Mgr., Bus. Dev., Simufact

**A**dditive Manufacturing began in the mid 1980's as so called Rapid Prototyping but has accelerated in usage after 2010. The technology has been significantly improved with a greater choice of hardware, larger build platforms, more materials and faster build rates. It is anticipated that there will be continued and accelerated improvement in the hardware (machines) over the next few years.

From today's perspective, it can be stated that we are watching the transition from "just another technology hype" to the next industrial revolution.

**The Advantages of Additive Manufacturing are Evident:**

- Increased role in Rapid Prototyping
- Production of small and medium lot sizes
- Design of optimized parts that would otherwise be impossible to manufacture
- Light components with integrated functions and high stiffness
- Lower material usage
- Lower Energy Usage, due to elimination of production steps

- Light weighting
- No need for expensive tooling
- Manufacture products from fewer parts, thus reducing part inventory
- Manufacture parts anywhere/Print on Demand/ Customization
- Repair of parts
- Make functionally graded materials (FGM)
- New & customized materials

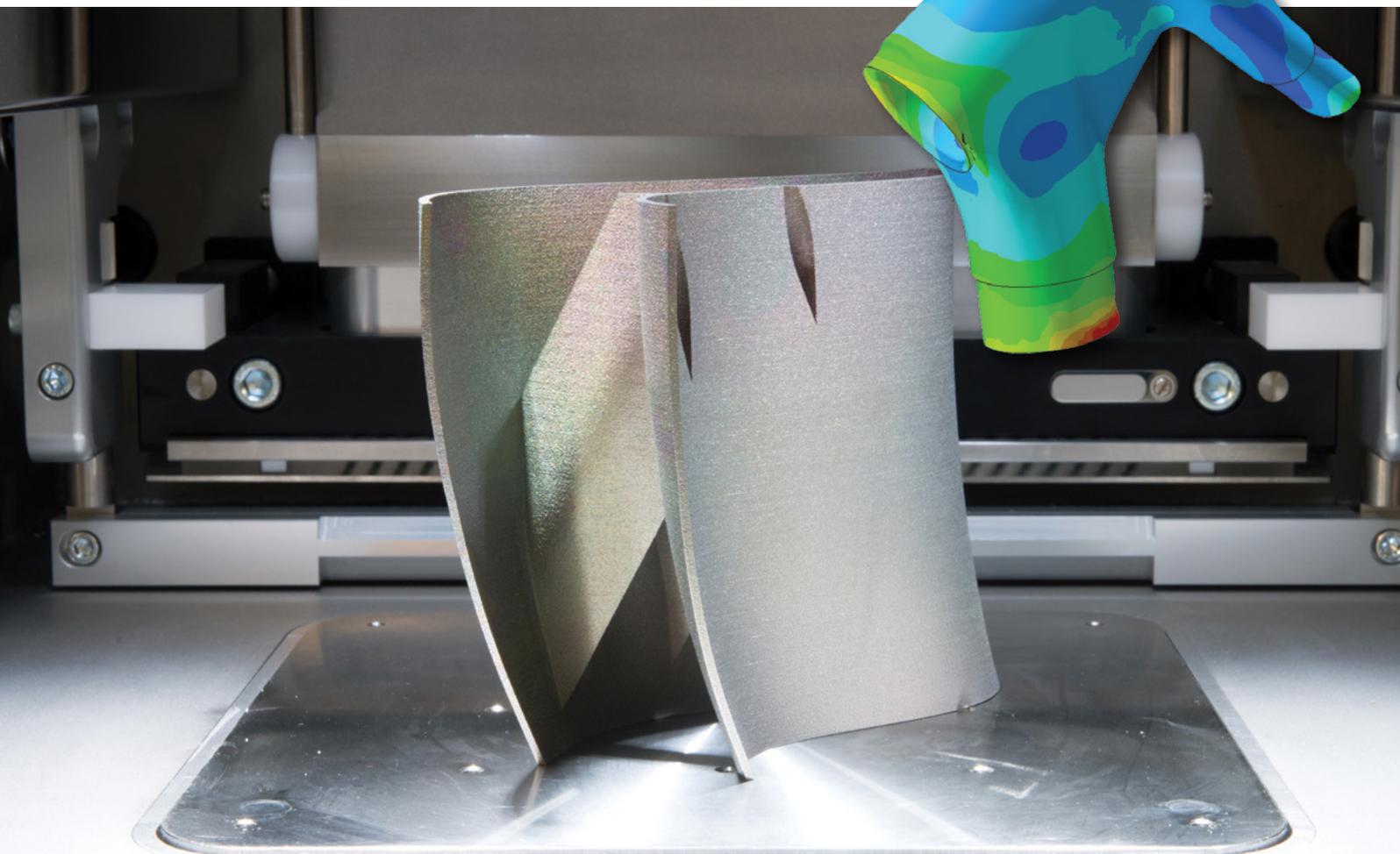
Based on this significant potential in terms of manufacturing effectiveness there is no industry which is not taking a close look at Additive Manufacturing Technology. Typical industries are automotive, aerospace, consumer products & electronics, medical, military & defense and many others.

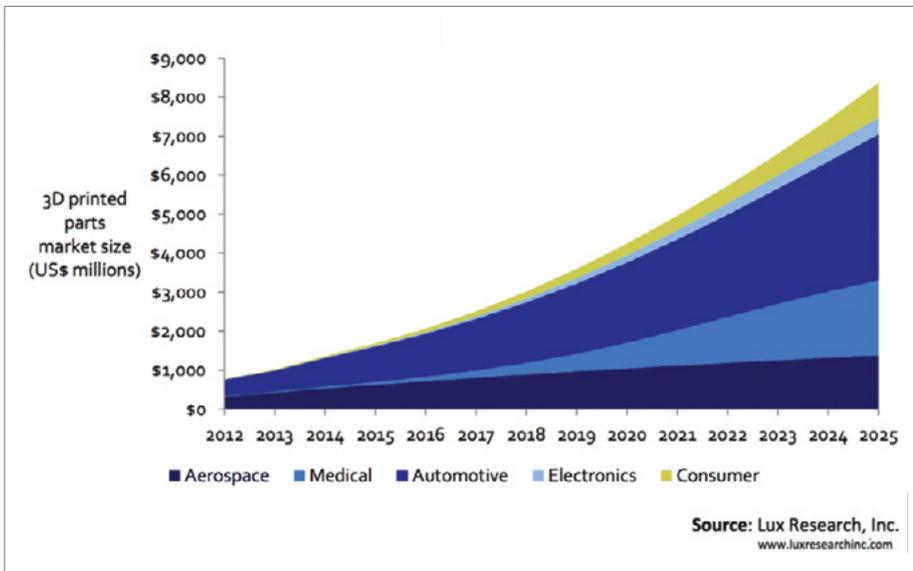
Even though AM is a very exciting technology, it is likewise extremely challenging. The general situation in the industry can be described as: budgets are available but no practical experience-yet. AM cannot be compared with traditional manufacturing processes such as casting, forging, machining or welding, where the engineers and shop floor people have decades of experience and can manage the processes based on their deep knowledge of the technology.

In AM the industrial managers together with the designers and the operators have to answer questions such as:

- What kind of machines to buy?
- What is the best plant layout?
- What are "AM friendly parts" considering parameters like lot size, material, complexity, dimensions, assembly, tolerances, cost & tooling time, and also considering the subsequent manufacturing steps in a total process chain?
- Can part counts in sub-assemblies be reduced?
- Can weight be saved without compromising part performance?

These are general strategic questions that each company must answer before a decision can be made to go for a strategic initiative that will influence the future competitiveness of the enterprise. When introducing AM as a new





Additive Manufacturing Market will grow to \$8.4 Billion in 2025



**Metal Additive Manufacturing is considered to be the next industrial revolution. It comes with many challenges- not just for the manufacturing enterprises, but also for the software suppliers that support the engineering process.**

production technology, major challenges arise on the shop floor when the parts are actually printed. Some of the challenges are:

- Achieving the final net shape – reducing the part distortion
- Dealing with the effects of residual stresses
- Structural quality of part performance
- Build Speed as one of the significant cost drivers- lower production rates

Having a closer look at the last item: assuming an hourly machine rate of 80€ and typical build times between 10 to 40 hours, one part per build would lead to basic part expenses between 800 and 3.200€ without consideration of the material, development number of business and HR overhead. Not to mention, the AM machines a company would need to produce 50, 100, or a thousand different products with lot sizes between 100 to 10,000 parts. It's evident that besides the improvements

of the technology itself- machine, material, process – there is a need for complementary tools to drive the engineering process.

[Simufact Additive](#) is a simulation tool from MSC Software, that provides a solution for structural behaviour during this process, and is using a three-level concept to meet all requirements of both industrial and scientific users. The three levels are:

- Macroscopic Scale
- Mesoscopic Scale
- Microscopic Scale

For each level of modeling (Macro, Meso, Micro), the implementation in Simufact Additive is designed to cover the whole process chain. There is an “external loop” and there are “internal steps” of the process chain. The external loop, like topology or design optimization at the front end, or machining, stress and fatigue analysis at the back end, is covered by additional software products from [MSC Software](#).

The internal steps within the AM process, which are entirely covered by Simufact Additive, are the build process itself, but additionally a subsequent heat treatment process, removal of the base plate and the support structure and HIP (Hot Isostatic Pressure).

Metal Additive Manufacturing is considered to be the next industrial revolution. It comes with many challenges - not just for the manufacturing enterprises, but also for the software suppliers that support the engineering process. Simufact Engineering and MSC Software have released a software solution to predict the most critical pain in metal AM - part distortion. The objective is to provide a solution for industrial process engineers to shorten their process development time and produce high quality parts with this novel manufacturing methodology, reaching the objective of printing parts “first time right.” ♦



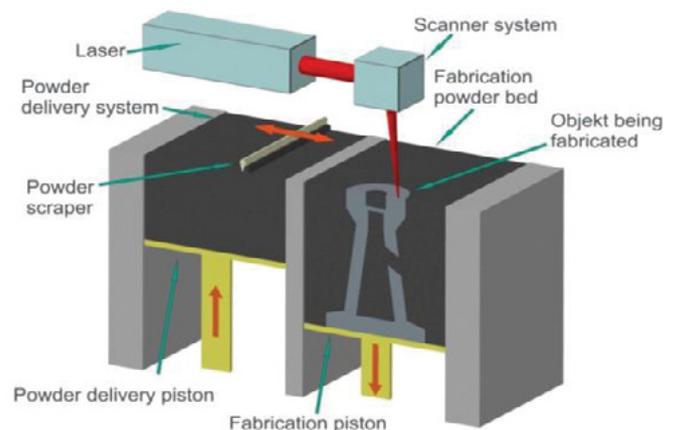
# simufact additive

## A New Tool for Simulating Metal Additive Manufacturing



by **Michael Wohlmuth**  
CEO, Simufact

**Dr. Patrick Mehmert**  
Product Manager, Simufact



Principle of a laser powder bed fusion AM machine (Fraunhofer IWU)

**W**e are witnesses of an interesting movement of building new things. Simulation tools that would allow us to get the parts first time right are very much a prerequisite for AM to really take-off as a true manufacturing process.

This movement has its challenges which includes distortion, residual stresses, and part quality. By replacing the current physical trial & error process with a holistic simulation approach, users will be able to address these issues in a more optimized manner. Engineers will ultimately be able to simulate the entire AM process with tools such as [Simufact Additive](#).

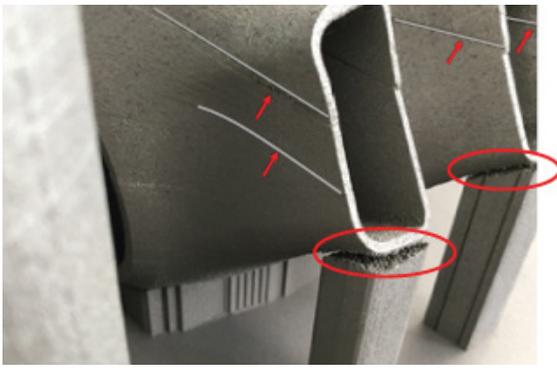
The oldest resin based technology – Stereolithography – goes back to the 1970s with a commercial utilization starting in the late 1980s. This new

AM “hype” is really a practice with 50 years of history. The difference today is, that AM has developed from a purely specialized prototyping approach to a wide spread use, due to the increased number of printing systems and improved technology. Plastic 3D printers are already affordable even for individuals while the emergence of metal printers increases the opportunities for real-life industrial applications.

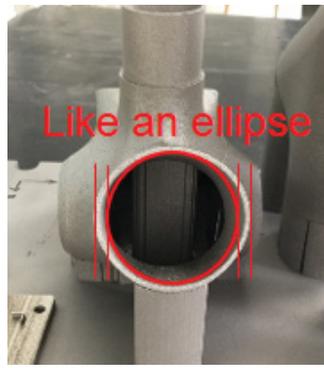
**When talking about metal AM there are mainly two different approaches: Direct Deposition & Powder Bed Fusion (PBF).**

**Direct Deposition** is in fact, a build-up welding approach. The main advantage of direct deposition fabrication is the possibility to add a large amount of material at a time to achieve a near net shape. The disadvantage of this is that only a rough semi-finished part is produced and relatively high efforts must be spent on manufacturing post-processing, such as machining, to achieve the target geometry.

**Powder Bed Fusion (PBF)** systems can deliver more sophisticated filigree parts with less or even no additional machining effort. This allows the production of



Typical failures and distortions



Round structure distorted to ellipse



**By replacing the current physical trial and error process with a holistic simulation approach, users will be able to address these issues in a more optimized manner.**

lightweight integral parts even with optimized bionic-like shapes that were not producible before with traditional technology. PBF methodology can thus reduce the assembly complexity and even integration of functionalities like movable components. For certain applications PBF AM parts can be produced lighter, faster, and cheaper than with traditional manufacturing technologies. Individually designed parts with small lot sizes can be produced quicker and cheaper than with traditional technologies.

However, metal powder bed fusion manufacturing faces many challenges. The main issues being distortions and high residual stresses. Distortion can lead to parts that are outside of the needed geometrical tolerance and need special post-treatment or might simply be scrapped. Furthermore, distortions can lead to a manufacturing abortion during the build, if the powder scraper collides with the part and is not able to apply another layer of powder. Residual stresses can lead to failure of the part, its support structures or the connection between them. Even if the part itself is not affected, broken supports or connections can, again, lead to undesired distortion.

Apart from these main pain points a long list of other challenges exist, such as, low relative material density, pores, insufficient powder binding, surface quality, strength and durability of the additively manufactured part. It is quite common that before a satisfying process can be identified, 3 to 10 or more manufacturing tests with different parameters have to be performed. To avoid further investment of time and costs these “trial & error” iterations should not be continued to find better or even optimal manufacturing conditions.

**There is a strong need for a manufacturing process simulation that helps to reduce trial & error iterations, thus reducing needed time & costs, and can help to identify further improved or even close to the optimum manufacturing conditions.**

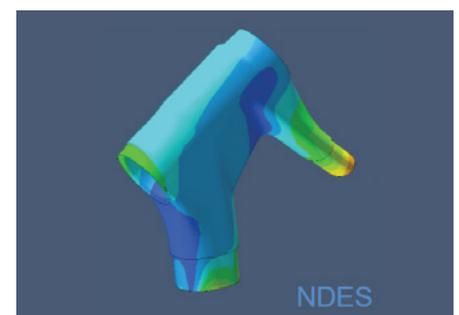
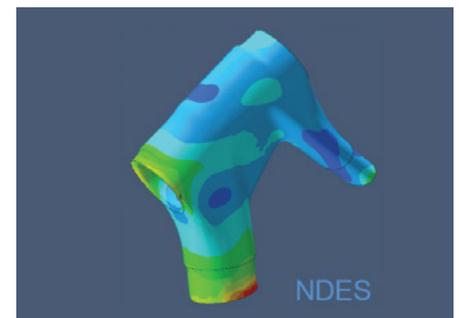
Simufact Additive is designed to cover the complete AM process chain. There are both “external loops” and “internal steps” of the process chain.

The first step can be to start with a topology optimization and derive a design, either manually or by automatic smoothing operations. The core manufacturing analysis steps can be seen in simulating building of the part, relieving stress by heat treatment, cutting off the part including supports from the base plate, removing the supports and

optionally performing a hot isostatic pressure (HIP) treatment. HIP is often used in aerospace applications to further densify the part and specifically, improve its fatigue properties. These core manufacturing steps within the AM process are covered entirely by Simufact Additive. Subsequent analysis steps can be machining, further surface treatment and finally stress and fatigue analyses based on the as-built conditions.

The external loops are covered by additional software products from [MSC Software](#). Data exchange interfaces also allow a coupling with third party software.

The purpose of simulating the process chain to include all sub-tasks is evident: This allows the user to predict the final distortion of the printed parts right after the entire AM process, including post-processing. Considering the complete process chain assures a high level of accuracy. ♦



Study of verifying support structures

# A Deeper Look into the Development of **Simufact** **Additive**



by **Dr. Hendrik Schafstall**  
CTO, Simufact

**S**imufact provides manufacturing process simulation software solutions for forming, joining, welding, and, most recently, additive manufacturing processes for metal-working industries. Simufact takes extremely sophisticated numerical simulations of physics and wraps it in an easy-to-understand, easy-to-use interface, designed with a production engineer in mind. Companies such as Audi use our software to virtually prototype the manufacturing process for every new car model, before the expensive first build process, which can waste millions of dollars and months of time in a physical trial and error process.

The intent of [Simufact Additive](#) was to provide engineers with a powerful and scalable software solution for the simulation of metal-based additive manufacturing processes. The purpose of the project was to utilize simulation in the 3D printing process to predict distortions and virtually eliminate them before the first part is ever printed. This includes the printing and subsequent cutting and hot isostatic pressing (HIP) processes. At the moment, industrial 3D printing is a slow and expensive trial and error process. In the aerospace industry, an

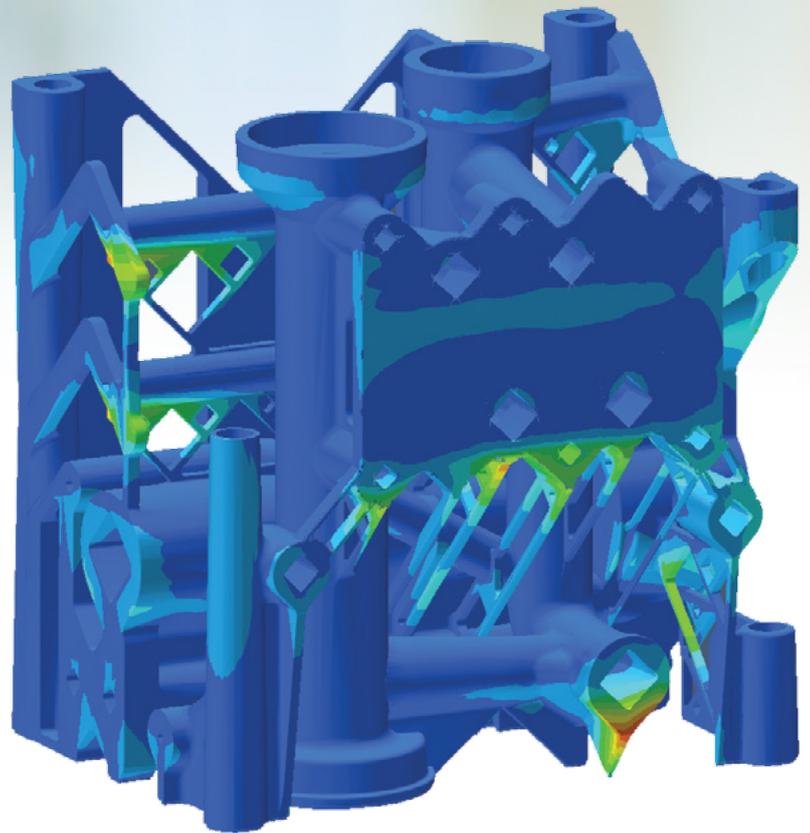
aluminum part can cost up to \$50K to print and a complex titanium part can cost up to \$150K taking into account machine time, material and labor. Besides this costly process, placement of the part incorrectly in the machine costs \$20K to \$50K. Our solution is proven to have excellent correlation to physical tests, helping our customers to achieve getting parts “first time right”. Our customers can make a more effective use of their 3D printing machines, many of which can cost up to \$1M.

Simufact developed an application-specific solver, based on MSC’s powerful nonlinear finite element [Marc](#) solver, that is able to capture the complete process chain in the

manufacturing environment and to scale the simulation based on the user’s requirements. Key drivers of this tool are accuracy and speed. Simufact has developed a completely new infrastructure specially dedicated to AM.

The software enables users to quickly predict the distortion and stresses of parts being additively manufactured by metal powder bed technologies during production and at the end of the manufacturing process chain.

With this prediction capability the main points in additive manufacturing are addressed. Distortion can lead to parts out of tolerances that can’t be used at all, or used only after costly post-treatment like milling down to the



INNOVATIONSPREIS-IT

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Simufact Additive has achieved the "BEST OF 2017" Innovation Award IT - presented by the German "Initiative Mittelstand"

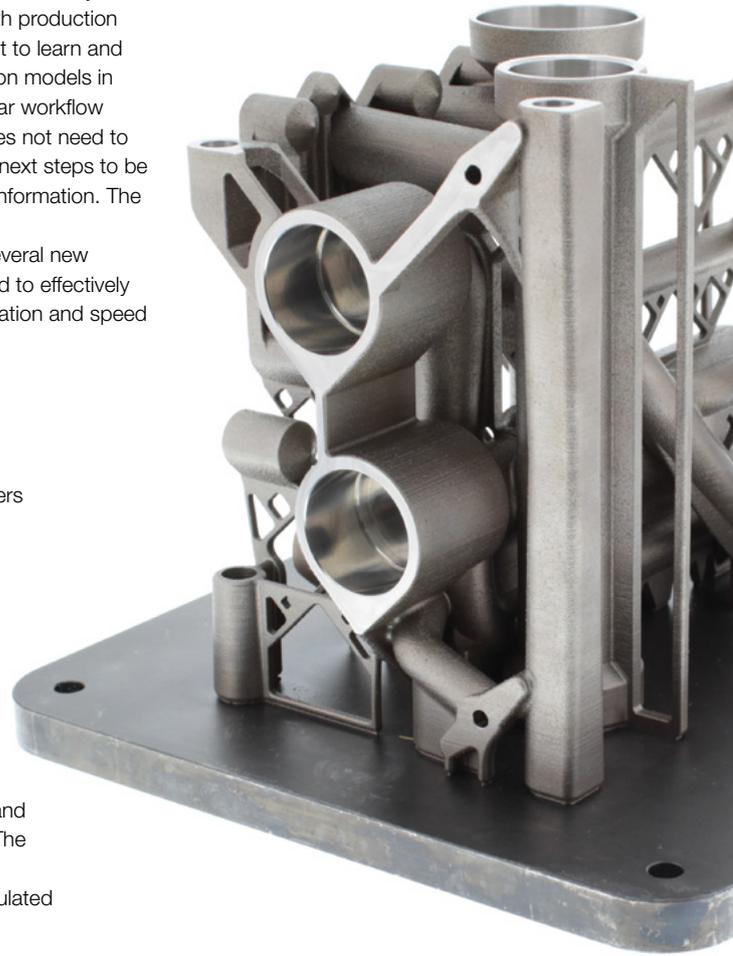
desired shape. Distortion can even lead to an AM build job absorption during production if the part interferes with the powder application mechanism. Unwanted high residual stresses can lead to failure of the part during production or to unintended additional distortion in the subsequent process chain, e.g. when cutting off the part from the manufacturing base plate.

The [Simufact Additive](#) GUI is user friendly intuitive, and was designed with production engineers in mind. It is very fast to learn and can be used to create simulation models in just a few minutes. It has a clear workflow orientation so that the user does not need to spend time thinking about the next steps to be performed and avoid missing information. The solver is an adaptation of the Marc non-linear FEA solver. Several new functionalities have been added to effectively manage the voxel based simulation and speed up the analysis approach.

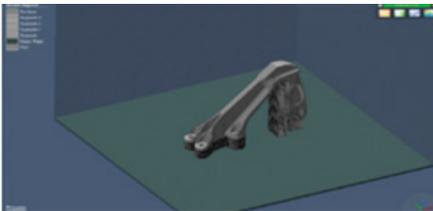
[Simufact Additive](#) optimizes:

- AM part designs
- Material selection
- Manufacturing Parameters
- Build-up orientation
- Support structures
- Process chain set-up

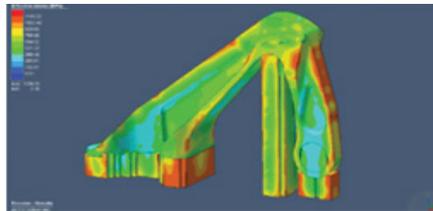
This enables the user to virtually simulate and optimize factors like setting parameters and materials, cutting direction and support removal, build up orientation, and support structure placement. The process below illustrates the entire process that can be simulated with [Simufact Additive](#). ♦



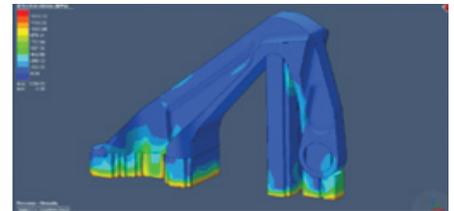
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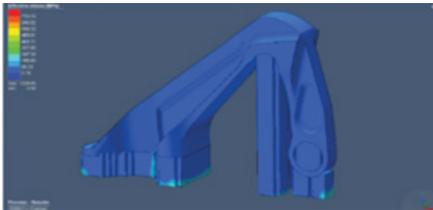
Cut from Plate



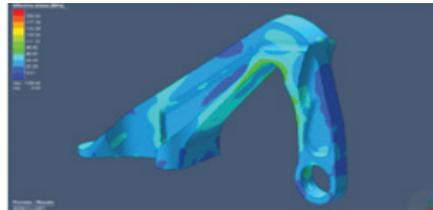
Heat Treatment



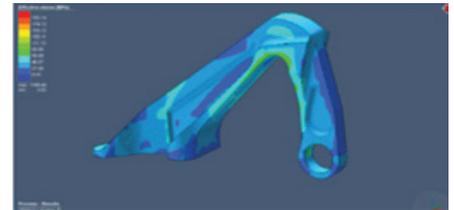
Cooling



Remove Supports



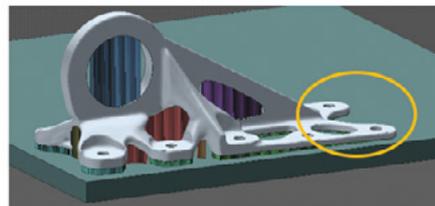
HIP



Process Chain Simulated with Simufact Additive



Companies such as Audi use our software to virtually prototype the manufacturing process for every new car model.



Compensated Design

**A**dditive Manufacturing by definition, opposed to subtractive methods, regroups a number of manufacturing processes - allowing to create parts from 3D numerical CAD models, building up the components in layers by depositing material. Hence, not requiring specific mold tooling design. Low volume, complex parts can be produced at fixed cost in less time. As lightweighting becomes a top design priority for the automotive and aerospace markets, the capability to reduce the number of parts by manufacturing an assembly directly is a promising source of gain. Lattice structures are also increasingly interesting the industry seeking the optimum mix of mechanical performance and low density. Such design opportunities offered by AM technologies can successively lead to weight reduction of several tens of percent.



by **Philippe Hebert**  
Application Engineer, e-Xstream

**Olivier Lietaer**  
Business Development Engineer, e-Xstream

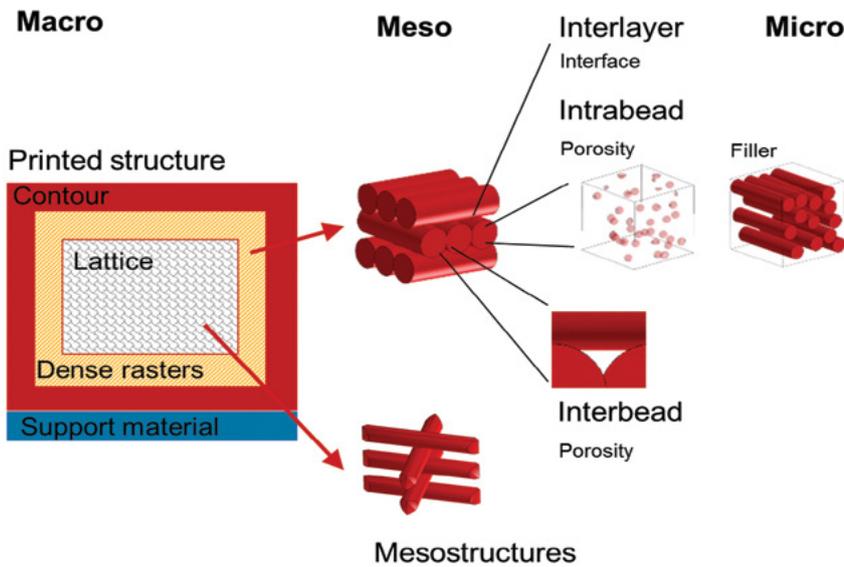
#### Other Advantages of the AM technology include:

- More integrated/functional parts
- Product lifecycle: reduced costs and time to market
- Onsite - On-demand production/ Customization
  - End-of-life products
  - Medical & dental
  - Aerospace
- Reduced material usage (lightweight design or less manufacturing waste)
- Reduced energy usage (no need to remove material)
- No need for tooling
- Agile & Lean development.

Until recently, the application of 3D printing was limited to rapid visual prototyping. [Additive manufacturing of plastics](#) is experiencing a paradigm shift as the industry is now looking into the technology as a full production technique to achieve tailored design but also new lightweighting solutions, which are not viable with other manufacturing methods. To unveil the full potential offered by the manufacturing technology, predictive simulation tools are required by process engineers and end-users. A simulation approach of the manufacturing process can help to quickly explore at virtually zero marginal cost the sensitivity of process parameters on the process quality and part fidelity or realize the impact of design decisions before the part is printed.

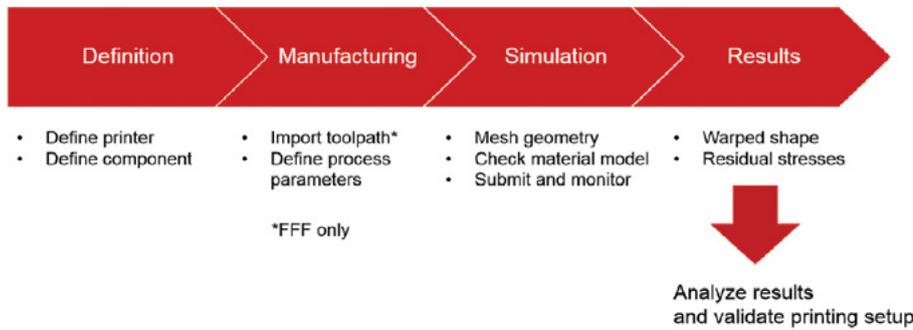
# Multiscale Modeling of AM Process of Plastics & Composites





Additive manufacturing is a multiscale challenge (Illustrated for the FFF process).

**The main goals of AM process simulation include predicting the final distorted shape of a part, the residual stresses distribution and the process-induced microstructure (such as porosity and fiber orientation – for reinforced plastics).**



Workflow in Digimat-AM to predict warpage and residual stresses for a given application.

As for FFF processes, the meshing procedure is based on voxels. Neighbouring powder is also modelled for actual part support. Overall, a parallelepiped containing the printed part and the neighbouring powder is generated. The thermomechanical simulation aims at modelling the building chamber environment of the SLS process, and relies on a multiscale thermomechanical material model.

e-Xstream Engineering is offering a holistic simulation chain for the additive manufacturing of plastics and composites with solutions for material engineering, process simulation, and part performance to the market. This integrative approach is needed to accelerate the adoption of AM by the industry and promote new innovative structural designs that are needed to save energy and weight. ♦

## Modeling Approach

The main goals of AM process simulation include predicting the final distorted shape of a part, the residual stresses distribution and the process-induced microstructure (such as porosity and fiber orientation – for reinforced plastics).

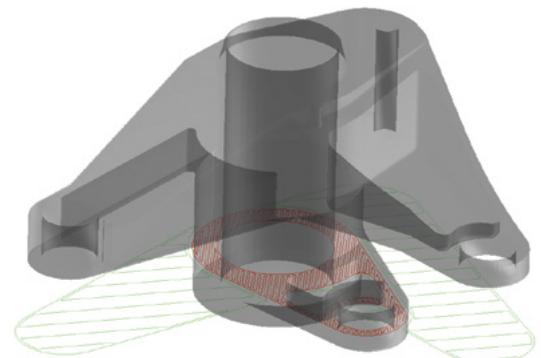
Overall, modeling the printing process thus requires to account for material state evolution, to model the stress build-up as well as the stress relaxation which can occur over time. Numerical predictions of warpage need to account for the process parameters – which can be a function of the type of AM technology considered – the material characteristics and the printing strategy (part orientation, toolpath, supports ...). Once the FEA simulation is performed, residual stresses can be obtained as well as the final deformed shape of the part.

Specifically, for the FFF process, information about the time deposition and the microstructure are deduced from the toolpath (typically, from GCode file) which is loaded and read in the software (Figure 3). The beads orientation is associated with the corresponding

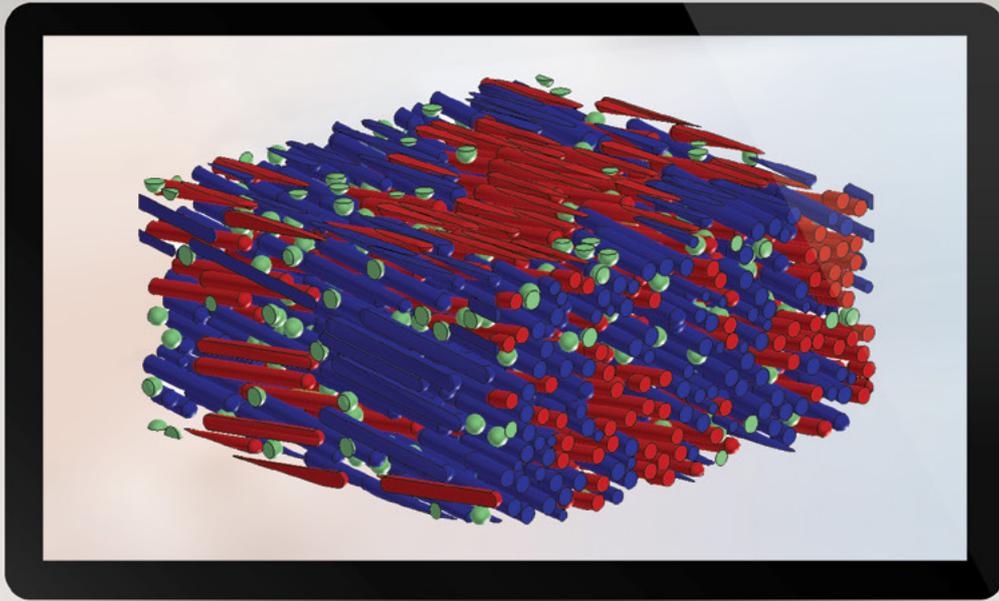
voxels and consistent microstructures are stacked up. These process-induced microstructures are dramatically influencing both the material properties and the structural performance, and in particular the failure. The porosity distribution is also deduced from the toolpath.

Selective Laser Sintering process consists in the sintering of powdered material using a laser heat source. The laser selectively fuses the powder by scanning cross-sections of the part. Once a layer is sintered, an additional layer of powder is deposited from the powder bed, and a new sintering step starts.

- Heating
- Layer deposition
- Laser movement and local temperature rise
- Powder sintering
- Heat diffusion
- Additional layer deposition, which can be repeated as many times as required
- Until global cool down



Toolpath loaded in the software to generate the process-induced microstructure. Green corresponds to support and red to part infill.



# Digimat 2017.1

Delivers First Simulation Chain  
for Additive Manufacturing Polymers



Building on its large experience with polymer modeling, with Digimat 2017.1, e-Stream is introducing the first simulation chain for additive manufacturing of polymers, Digimat Additive Manufacturing (Digimat – AM). Additive manufacturing of plastics and composites is evolving from rapid prototyping to industrial production. Printer manufacturers, material suppliers, and end-users need predictive simulation tools to bring the additive manufacturing efficiency and performance to the next level required by the industry. Digimat- AM has already been recognized with a JEC Innovation Award in the software category for its innovation and market potential.

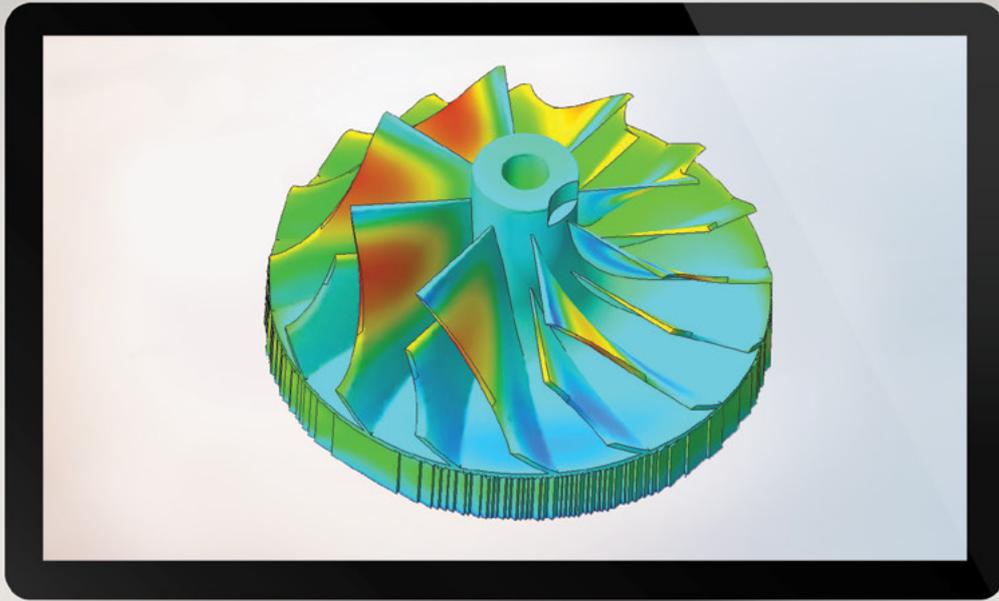
Digimat-AM, the latest edition to the Digimat platform, is the ultimate simulation solution for manufacturing process of Fused Filament Fabrication (FFF), Fused Deposition Modeling (FDM) and Selective Laser Sintering (SLS) of reinforced materials. For printer manufacturers and end-users, the part fidelity is the top challenge to overcome. Digimat-AM allows the engineer to predict warpage and residual stresses of a polymer part as a function of the manufacturing process parameters. With Digimat-AM, users can further optimize the process and minimize the part deformation right at their fingertips. Virtual engineering is the solution to minimize printing trial and errors because it enables the user to explore the process sensitivity to manufacturing parameters.

By applying multi-scale material modeling techniques to the additive manufacturing of polymers (unfilled and reinforced), Digimat's virtual material compounding and characterization is a key enabler for customers developing new materials. Virtual engineering allows the engineer to significantly reduce physical tests, understand the key parameters driving the material's behavior, and easily create new material systems, such as lightweight lattices.

*"With solutions for materials development, process simulation, and printed part performance, Digimat Additive Manufacturing is a completely innovative solution that's fully dedicated to reinforced plastics and composites, allowing its users to 'print it right the first time'" - Roger Assaker, CEO of e-Stream engineering, Chief Material Strategist of MSC Software.*

## Improved Efficiency

Digimat's latest release not only opens new horizons and a new way of designing, but also brings some nice additional features. Digimat's material model reverse engineering capabilities have been extended for creep and crash performances to better support material engineers. Structural engineers now benefit from significant CPU reduction when simulating the as-manufactured performance of MuCell® components, or when simulating creep of plastic parts.



# Simufact Additive 2

## Optimization of Process Chain for Metal AM Simulation



Simufact Engineering, an MSC Software company, has released Simufact Additive 2, a new version of its simulation solution for metal-based additive manufacturing. The software provides a series of capabilities covering powder bed fusion processes that deliver more certainty in achieving a reliable additive manufacturing process for high quality parts.

### **New Capabilities Include:**

- Calibrating with cantilevers (physical testing) - a fast optimization algorithm calibrates the inherent strain values allowing for the accurate prediction of the distorted part. The unique set of strain values represent a particular combination of materials, machines, and scanning strategies that provides reliable simulations for complex additive components.
- Individual positioning of parts in virtual build space – this release provides special handling to determine the most efficient positioning of parts on the base plate, and allows for iterations to be made that optimize the build-up orientation. Positioning the part is very intuitive due to the easy-to-use interface.

- Support of orthotropic material properties - enables a more realistic representation of support structures stiffness. Coarser meshing provides reliable results in addition to faster calculation times.
- Optimization of the additive process chain - an effective, fast optimization of the whole process chain, including printing, heat treatment, cutting/removing of supports, and HIP. With this new release, users are now able to stop and re-start the simulation process at any stage of the process chain. Each process step can be optimized separately based on the previous results.
- Simulate HIP processes - densification of components can now be simulated. This process reduces porosity and provides longer life to products.

Comparison with physical testing – the new release now enables users with a comparison of simulated parts with the target design, or with 3D measurement data as a reference. Users can also evaluate deformations relative to the reference geometry.

**Try FREE for 30 Days!**

[www.mscsoftware.com/simufact-additive-free-trial](http://www.mscsoftware.com/simufact-additive-free-trial)

# e-Xstream & Solvay Win The 2017 JEC Innovation Award

[e-Xstream engineering](#), an MSC Software Company and co-winners Solvay Performance Polyamides and Solvay Specialty Polymers have been recognized with a [JEC Innovation Award](#) for launching Digimat Additive Manufacturing. Awarded in the software category, the launch was recognized for its innovation and market potential.

"We're honored to be recognized as an industry innovator by JEC, and look forward to continuing our modeling leadership with Digimat Additive Manufacturing to help address the global industry's need to transition from prototyping to actual manufacturing" said Roger Assaker, Chief Executive Officer, e-Xstream. "With solutions for materials development, process simulation, and printed part performance, Digimat Additive Manufacturing is a completely innovative solution that's fully dedicated to reinforced plastics and composites.

Today the development time is very long, because the as-printed material properties are closely related to the process conditions and the process-induced microstructure, such as printing direction and porosities distribution. By applying multi-scale material modeling techniques to the additive manufacturing

of polymers (unfilled and reinforced), Digimat's virtual material compounding and characterization is a key enabler for customers developing new materials. They are now able to significantly reduce their physical tests, understand the key parameters driving the material's behavior and easily create new material systems, such as lightweight lattices, and open the door to even more innovative designs.

For printer manufacturers and end-users, the part fidelity is the top challenge to overcome. With simulation tools that enable optimizing the process and minimizing the part deformation, the technology reliability and the integration of its use into the industry are at the engineer's fingertips. Virtual engineering is the solution to minimize printing trials and errors because it enables the user to explore the process sensitivity to manufacturing parameters.

*"Being part of the launch of Digimat Additive Manufacturing aligns with our strategy to play a leading role in enlarging the portfolio of available high performance materials."* said Brian Alexander, Head of Additive Manufacturing for Solvay's Specialty Polymers Global Business Unit.

## About Solvay

An international chemical and advanced materials company, Solvay assists its customers in innovating, developing and delivering high value, sustainable products and solutions which consume less energy and reduce CO2 emissions, optimize the use of resources and improve the quality of life. Solvay serves diversified global end markets, including automotive and aerospace, consumer goods and healthcare, energy and environment, electricity and electronics, building and construction as well as industrial applications. Solvay is headquartered in Brussels with about 30,900 employees spread across 53 countries. It generated pro forma net sales of € 12.4 bn in 2015, with 90% made from activities where it ranks among the world's top 3 players.

## About JEC

The JEC Innovation program was created in 1998 to help identify, promote, and reward the most innovative composite solutions worldwide. The selection criteria for the JEC Innovation Awards are technical excellence, exemplarity of the chain of partners, market potential and originality. The ultimate goal is to recognize the efforts being made towards the advancement of the composite industry.



# Meet e-Xstream Engineering, an MSC Software Company

This software and engineering services company focuses 100% of its business on the multi-scale modeling of reinforced plastics and composites. The major aerospace and automotive companies from around the world turn to e-Xstream to model their advanced materials, cars and airplanes, a job to which CEO Roger Assaker and his team devote themselves with passion and confidence.

So how did e-Xstream engineering get here? Assaker sat down to give us the story:



**Roger Assaker**  
CEO, e-Xstream Engineering

## Tell us How this Story Begins.

I grew up and lived in Lebanon, the youngest of three brothers. I decided to go to university abroad and thus followed my brothers to Liège where I started studying Aerospace Engineering. One of my brothers was actually working at Solvay's headquarters in Brussels and helped me get a two-month internship there.

I studied in Liège and then took a Ph.D. in Louvain-la-Neuve in the area of semiconductors for electronics and applied to digital simulation. During the last year of my Ph.D. studies, my brother moved to Luxembourg and took a position at Goodyear. I knew the company had some open positions and I wanted to try the interview process to see how it felt like to enter the working world, and I got the job. So I decided to move to Luxembourg, start working, and finish my thesis at the same time. I stayed with Goodyear five years as an R&D Engineer in the Computational Mechanics Group. I also started an M.B.A. program by taking evening classes at Sacred Heart University in Luxembourg.

I quickly realized that working in a big company wasn't really an ideal life for me, I took a risk, and left Goodyear to start my own company in 2003.

## How was e-Xstream Born?

During my time at Goodyear, we invited one of my ex professors, Issam Doghri, to give a presentation about material modeling.

While I was pursuing my Ph.D. degree, I assisted him and gave some courses in solid mechanics and strength of materials. In that moment, we reconnected and decided together to create e-Xstream engineering.

On one side, Issam's research at the University of Louvain focused on material modeling and micromechanics. On the other side, I was already working on a business plan to start a company, this Business Plan became e-Xstream engineering. This was a perfect match. I took the lead of the business and Issam the lead of the R&D.

The business plan I wrote won competitions at the national level in Luxembourg (123 GO) and Belgium (4x4 pour Entreprendre) and at the European level (Eurowards). This gave us the first push and allowed us to get a good promotion as well as three investors.

We also received continuous financial support from the Luxembourg Ministry of Economy and the Walloon Region (1st Spin-off,...), which truly helped us reach our goals.

## What were the Next Steps?

The first clients I acquired were Solvay and Goodyear. Then the customers' pool and turnover kept growing fast throughout the years. We have become the key player in the materials modeling segment that included some of the biggest names from the Aerospace and Automotive industries amongst our clients. I started by opening our first two offices in Belgium and in Luxembourg, although the majority of my customers are international players.

In September 2012, I sold e-Xstream engineering to MSC Software, the pioneer of numerical simulation based in Newport Beach, California. With MSC, we continued to grow the company by doubling our headcount all around the world and tripling our revenues globally. This was only possible thanks to a strong team and to a continuous stream of award winning innovative solutions.

The JEC innovation award for our Additive Manufacturing is the last of a series of awards including 2 other JEC Innovation awards and the R&D 100, the "Oscars of innovation".

## What is your Company's Philosophy?

Although we are almost 60 people today and a 14 years old company, we still have start-up like values. Our motto is "work hard, play hard" and we mean it. Although, we gather some of the most experienced engineers and people - some have 30 years of experience and have worked for the biggest international aerospace and automotive companies - the atmosphere



is chilled, fun, young, and dynamic. I am today really proud of my team and the work they accomplish!

## Where do you see the role of Luxembourg in the Composites Industry?

The research around materials is part of Luxembourg's strategy to diversify. Luxinnovation's Materials & Manufacturing Cluster is tackling the topic. The Ministry of the Economy and the Ministry of Research has just created a National Composite Center in Bascharage, just across the parking lot from our office. Our activities fit perfectly in this national picture and initiatives as we have been doing research and development on this topic since 14 years now.

## What does this Award Really Mean to You?

It is a global recognition of our first steps in the Additive Manufacturing field.

The 3D Printing industry is growing around 30% every year and companies' interest for this solution has subsequently increased too. The global value of the industry is currently estimated to reach over \$10 billion by 2021.

I remember talking to a lot of companies for which the barriers to 3D printing were threefold: the cost, the printing time and the variety of materials. Therefore, we decided to create an ecosystem of companies including the stakeholders involved in the process: printing machines makers, materials makers and the end-users. This resulted in the creation of a new product, recognised today, at its early beginning, by the biggest players on the market. This award also gave us the strength and confidence that we can now push the development of the solution even further. ♦

# MaterialCenter for Additive Manufacturing



by **Leo Kilfoy**  
 General Manager,  
 Engineering Lifecycle  
 Management,  
 MSC Software

**A**dditive Manufacturing is one of several technologies providing the backbone for digitizing manufacturing. AM promises benefits of distributed manufacturing, production speed, lower cost, reduced part count including reduction in tooling and fixtures for complex geometries, product specialization & customization in designs and variants, and the ability to produce parts that could not be manufactured easily with traditional manufacturing methods.

In order to realize the full benefits of [Additive Manufacturing](#), one of the greatest challenges is producing repeatable and consistent quality parts. Part quality is driven by the variation from the “as manufactured” part. Variation stems from several factors, including the Additive System, Material, Build Information, Part Information, and Process Parameters. As a result, parts need to be rigorously qualified, which is a costly and time consuming process that results in reduced realized benefits from Additive Manufacturing.

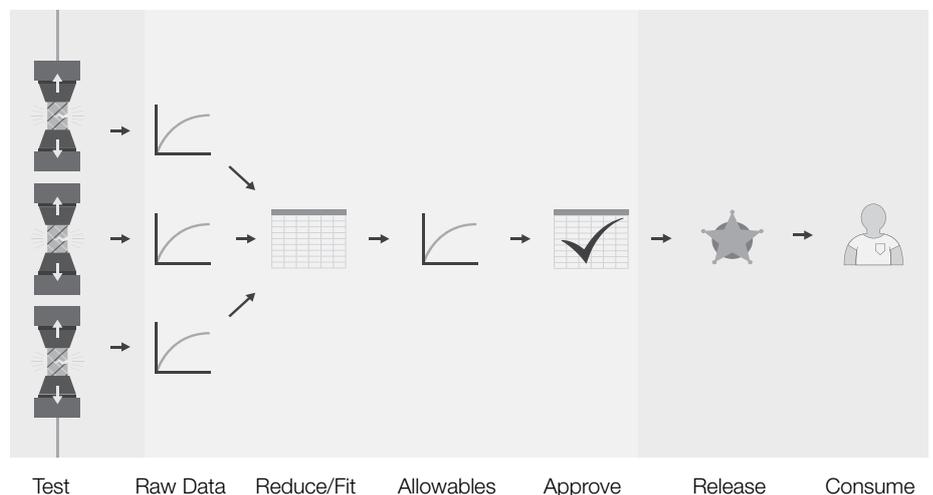
Understanding the variability in manufacturing and process parameters is critical to determine quantifiable material properties and part performance.

Traditional material characterization begins with testing materials, often times in batches (typical of coupon level testing) to account for variability in material performance. The test data is then reduced into engineering properties using statistical methods to account for variation. Finally, the material properties are used in design by engineering. The traditional method assumes the influences in the manufacturing process are within a sufficient tolerance to maintain statistical confidence. We will refer to this approach as “Right of Test” as shown in the figure below, which illustrates the steps from test to user.

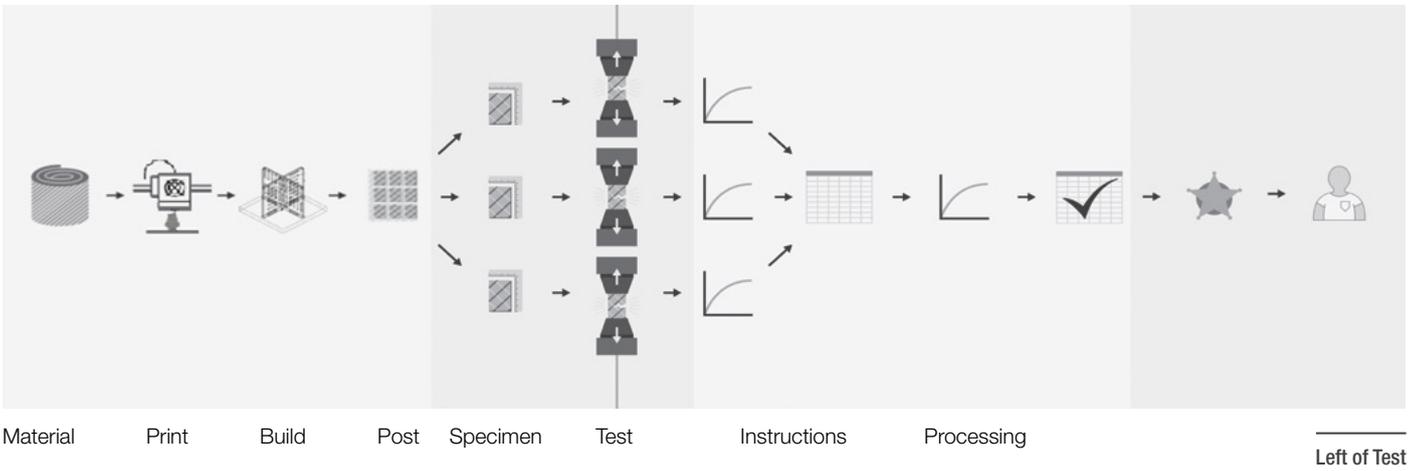
This approach works well for materials built with traditional manufacturing

methods, where the manufacturing process parameters are well understood and controlled. However, in the case of Additive Manufacturing, the inputs to the process are more numerous and play a much larger role in the statistical variation of material properties measured across batches. The variability of the process allows the material and part performance to be tailored and optimized as it is used in a design, but also presents a unique challenge in part consistency.

Being able to quantify the variability in manufacturing processes is critical to predicting material properties and part performance. It is essential to capture all the information, both “Right of Test” and “Left of Test” to fully characterize a



Right of Test



coupon, specimen, or part. For Additive Manufacturing, it is critical to capture both input and in situ data for:

- Additive System (manufacturer, model, software version, machine age and history, etc.)
- Additive Material (manufacturer, type, grade, size, etc.)
- Build Information (operator, condition of build plate, location on build plate, etc.)
- Part Information (CAD/STL file, g-code, dimensions, internal structures, etc.)
- Process (number of shells, layer height, raft, supports, temperature, power, etc.)

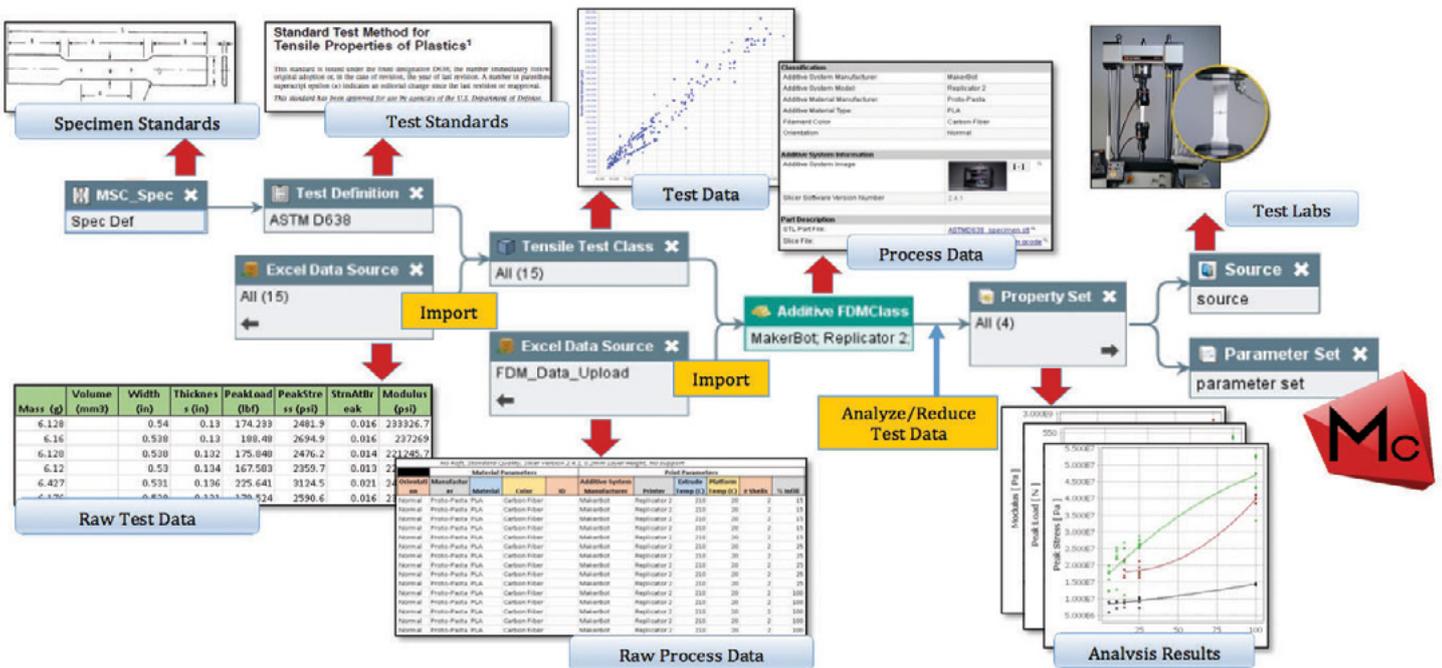
A complete trace from Fabrication (Left of Test), Test, Material Engineering (Right of Test), and Upstream Engineering represents the complete lifecycle stages. Today, much of this data is captured

in “Travelers” during the material manufacturing process and is often disconnected from the as tested data. For manufacturing approaches that are sensitive to process parameters, such as Additive Manufacturing, this information is vitally critical to capture in a traceable methodology to develop a quality system for certifying Additive Manufactured parts.

MSC’s [MaterialCenter](#) plays a critical role as the backbone across the entire Additive Manufacturing process allowing a single system to capture all manufacturing process parameters, eg: “Left of Test”, and correlate the outcome of a tested part to the inputs from the build. Data collected is then statistically reduced and used as design allowables in Finite Element or Material models to predict the behavior of parts and assemblies. Finally, the virtual test data

**It is essential to capture all the information, both “Right of Test” and “Left of Test” to fully characterize a coupon, specimen, or part.**

generated from analysis is fed back into MaterialCenter and overlaid with in situ monitoring information to validate the part as it is being built. MaterialCenter covers the full scope of materials lifecycle, such as materials development program and material usage across the lifecycle of the product from concept to sustainment. ♦



# Sinterline<sup>®</sup> Prototyping by Solvay

Ultimate strength prediction of a plenum under pressure produced by selective laser sintering



by **Sylvain Mathieu**  
Software Dev. Engineer, e-Xstream  
**Dominique Giannotta**  
Project Director, Solvay EP

**S**olvay, a global leader in advanced polyamide solutions, is the principal material sponsor for the Polimotor project. It aims to open the way for a technological breakthrough in the automotive sector by replacing up to 10 metal parts by plastic materials in the engine Polimotor 2 engine.

Among the manufactured plastic parts, the Polimotor 2 engine will feature a 3D printed plenum chamber produced through selective laser sintering (SLS) by using a Sinterline<sup>®</sup> Technyl<sup>®</sup> polyamide 6 (PA6) powder grade reinforced with a 40 percent loading of glass beads.

The target is to demonstrate that the plenum plastic part (manufactured with this technology and material) can perform with the same reliability as its injection-molded counterpart.

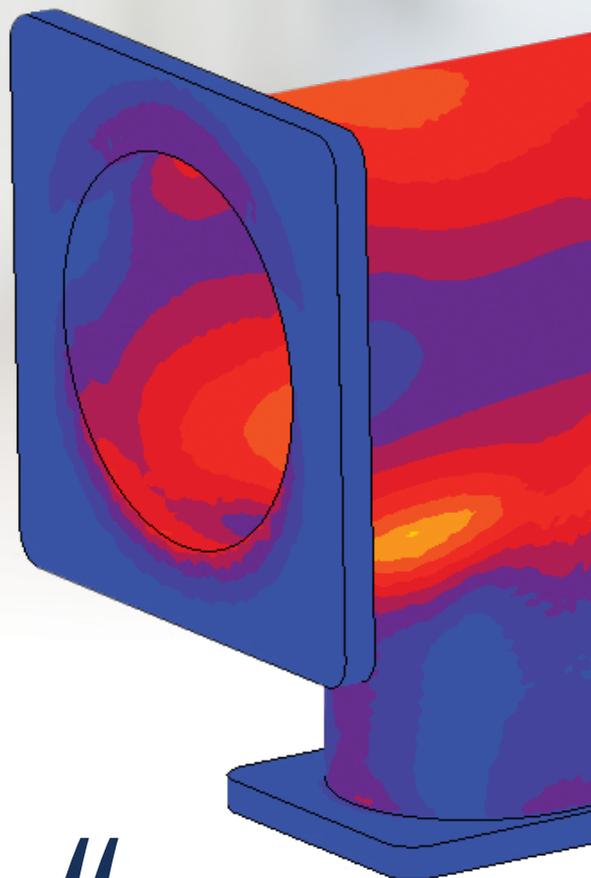
## Challenge

Due to the fact that parts are built of layer superposition without the need of support materials, laser sintering can quickly produce components that integrate complex internal features and functions. However, the direction in which the part is built greatly affects the printed part strength. Although the printed material behavior is not affected by the building

direction, its ultimate strength is reduced in the stacking direction. This issue is inherent to additive manufacturing processes, as successively deposited layers are not perfectly bound together.

The impact of the produced part orientation in the build chamber of SLS devices, and AM processes in general, must not be neglected and this new parameter influence must be evaluated.

In the image below, the plenum has been printed in a peculiar direction due to the limited space available in a building chamber: this will be taken into account while predicting the ultimate pressure load it can sustain.



**The designed plenum should sustain the working load conditions and may be redesigned by topology optimization in order to lighten the structure while taking advantage of the 3D printing technology.**



Polimotor 2 Plenum printed with Sinterline<sup>®</sup>



### Solution

- Create and calibrate the material behavior using the appropriate constitutive law. The glass beads are modelled using an elastic law while the pressure-dependent Drucker-Prager model is well suited to catch the matrix behavior.
- Fully characterize the failure surface using the appropriate failure criterion. The failure surface shape, specific to 3D printed material, can be well fitted with a generalized version of the Tsai-Wu transversely isotropic failure criterion.

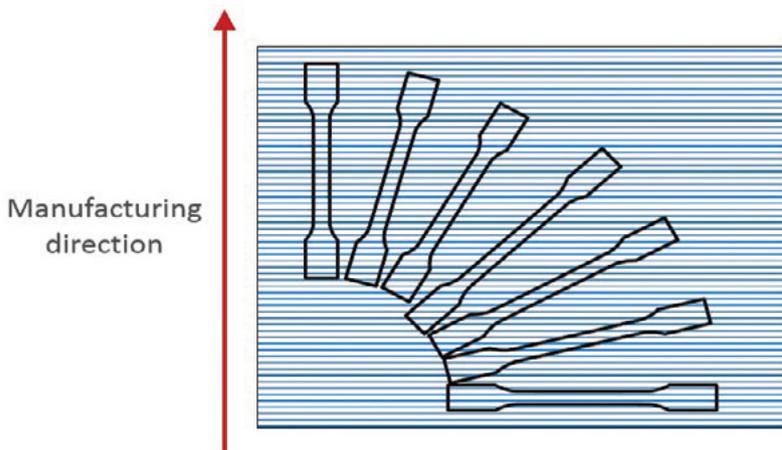
- Perform a coupled MSC/Digimat AM calculation to establish the ultimate pressure load the part is able to withstand.

### Results/Benefits

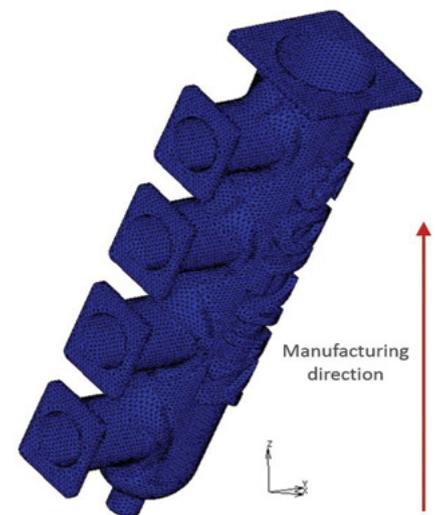
- Precise description of the material behavior and failure surface
- Study sensitivity of the part strength to its orientation in the build chamber
- Avoid producing parts that do not meet the strength requirements by taking into account the specificity of 3D printing processes

### Results Validation

The maximum pressure load sustainable has been numerically predicted to 9.1 bars, whereas 3 bars has been experimentally applied without failure in the same environmental conditions. The designed plenum should sustain the working load conditions and may be redesigned by topology optimization in order to lighten the structure while taking advantage of the 3D printing technology. ♦



Manufacturing direction vs. various tensile samples



Manufacturing direction of the plenum

# Design Optimization

## “Don’t Believe the Hype!”



by **Dr. Steffan Evans**  
Lead Engineer, Evotech

**T**here are many companies who would like to have designers and engineers believe that their tools have the magic “Optimized Design for Print” button - i.e. it doesn’t matter whether you have any clue as to what an efficient structure needs to look like (or know how to analyze one), if it’s been through our fancy black box solver then it’ll be fine. Real design optimization doesn’t work like that. Yes, there are tools, some simple and some hideously complex that can help, but if the output cannot be justified using basic engineering fundamentals and load path analysis, then it’s unlikely to be optimum (two points joined by a straight line under

axial load need a constant cross-section, anything else is just computational nonsense. That said, there are many structures which are indeed highly-complex, in terms of potential design space, interaction with surrounding structure, and multiple loading cases/environments. Of course, AM and Design Optimization allows engineers to explore this design space to understand what is efficient and ultimately, optimum.

Therefore, standard optimization tools are available for conceptual and detailed design space exploration. The key is to use the Design Optimization strategy as an engineering tool, and to clearly understand what the output is saying, not just blindly accept the answer as “computer knows best.”

In terms of the Design Optimization for the AM bicycle chain set, we explored several different techniques

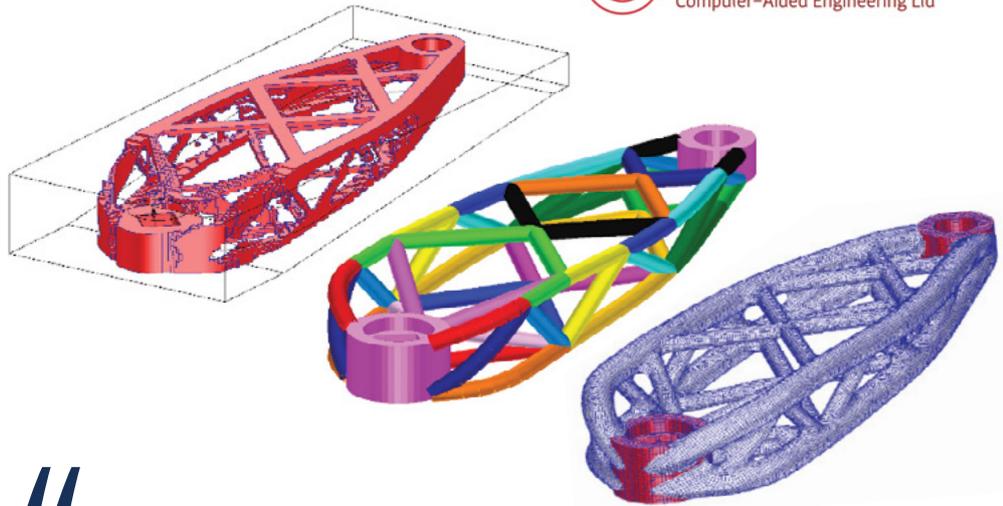
in understanding the optimum material layout for our design space and loading scenario. This was focused on the strategic development of a conceptual design (yes, topology optimization), followed by a detailed design based on a gradient-based bar/shell sizing approach to finalize the geometry for manufacture. One important aspect of the approach was to consider the fatigue properties of Ti6Al4V, which was qualified following significant coupon testing.

The final design was made up of a hollow structure with internal web supports. The thickness of these structures could be re-calculated for mass-customization using the power meter loading profiles for any given rider. Additionally, the overall geometry (length/pedal spacing) could be easily updated for rider ergonomics & ready for printing. We shied away from lattice structures, due to notoriously high levels of uncertainty under fatigue loading.

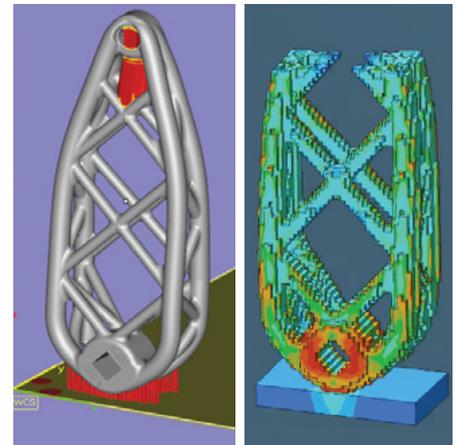
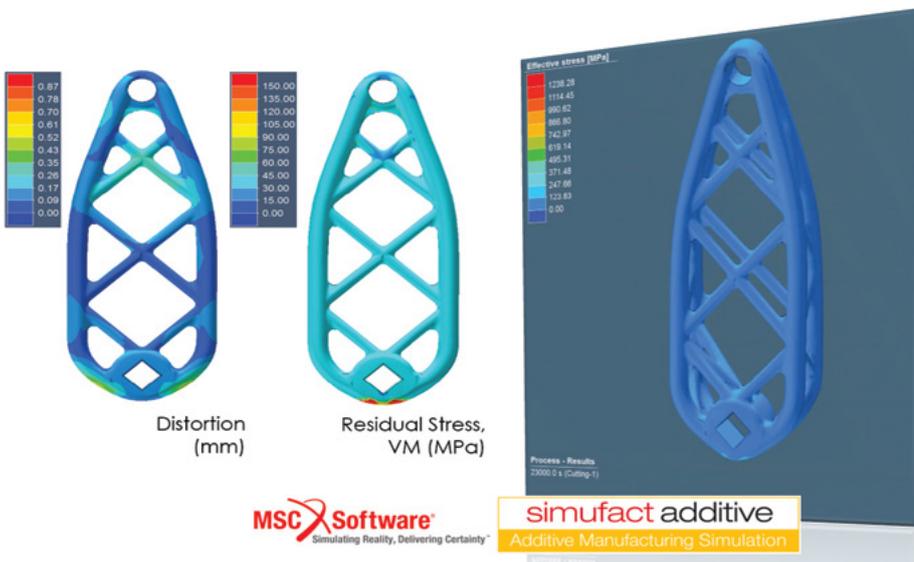
## Manufacturing Simulation ('Optimum Design, but Can We Make It?')

We were fortunate to have access to a FEA-based simulation software, [Simufact Additive](#), to model the AM process, recently developed based on many years of experience with welding simulation. It uses the inherent strain method to predict the part distortion and residual stresses in a time-effective way. The full analysis involved the multi-stage consideration of i) build, ii) support structure and base removal and iii) heat treatment of the finished part.

The overall outcome of the manufacturing simulation allowed us to better understand the physical process, thus building confidence in the design and downstream behavior. With some machine coaxing, we could build several test parts, which well represented the design intention. Once built, the internal powder within the hollow sections was drained through a hole in the threaded area of the pedal boss.



**The overall outcome of the manufacturing simulation allowed us to better understand the physical process, thus building confidence in the design and downstream behavior.**



Physical Testing



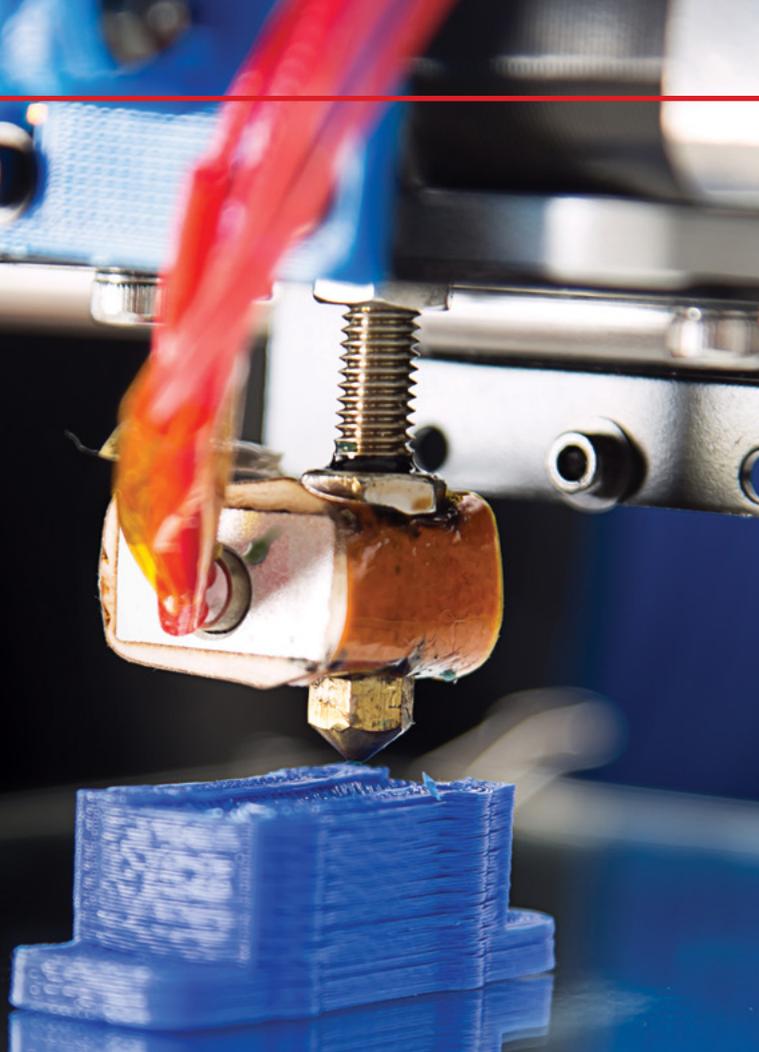
Testing of the finished chainset was performed using an ISO pedal fatigue test rig at an approved test house. The physical result demonstrated a failure stress within 1.3% of the target, thus demonstrating a highly-robust design process, which is often difficult with fatigue testing. A comparison between physical and predicted failure was performed with a very good correlation between the test and FEA data.

### About

Dr. Steffan Evans is Lead FEA Engineer at Evotech Computer-Aided Engineering Ltd, a UK-based Engineered Product Development Consultancy Company, specializing in Advanced FEA and Design Optimization.

More information is available at [evotechcae.com/am\\_development\\_life\\_cycle](http://evotechcae.com/am_development_life_cycle). ♦

# Simulating Effects of Warpage



by **Bender Kutub**

Senior Additive Manufacturing Research Engineer, Strataysys

**Olivier Lietaer**

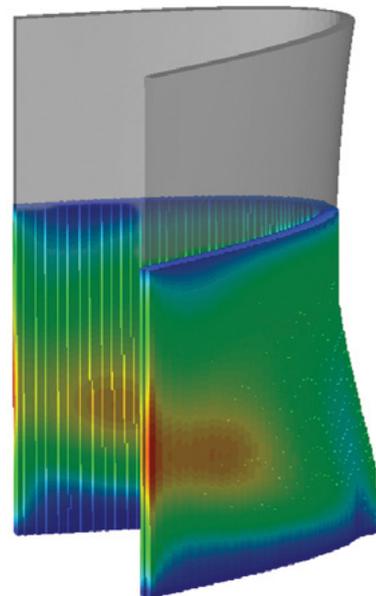
Business Development Engineer, e-Xstream

For more than 25 years, [Strataysys](#) has been a defining force and dominant player in additive manufacturing – notably inventing the Fused Deposition Modeling (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® (fused deposition modeling) is becoming the technology of choice for 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.

## Challenge

To unlock the full value additive manufacturing has to offer, simulation tools are needed to predict and mitigate part warpage as well as realize the impact of design decisions on the manufacturing process before the part is printed. Several challenges face the development of this process simulation:

- The complex thermomechanical loadings that 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 behavior – typically inducing anisotropy.



Virtual printing of the composite tooling in Digimat-AM

- The thermal history of the material deposition generates differential shrinkage between adjacent beads or layers that affects the end tolerances of the part.



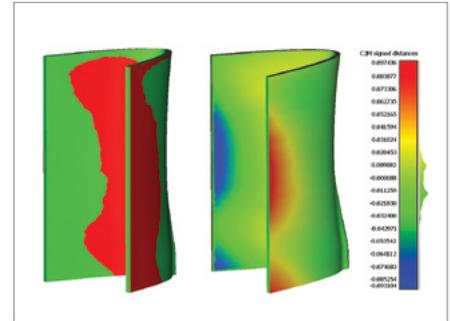
For engineers to unlock the design freedom that additive manufacturing offers, they need tools for accurate and effective analysis. Working with e-Xstream, we're enabling 3D printing to become a high performance production technology.



### Solution

Stratasys is working with e-Xstream to create FDM process simulation via a multiscale approach as a function of process setup and material choice:

- Solve a fully coupled thermomechanical problem of the deposition process to identify the warpage behavior of the printed material accounting for thermal exchanges inside the printer build (conduction, convection and radiation)
- Load the toolpath issued from the manufacturing processing software and extract information about the deposition sequence
- Model via micromechanics the heterogeneous material microstructure as a function of the toolpath (e.g., porosity volume fraction and orientation)
- Predict the resulting warpage induced by the printing process
- Iterate the design and optimize the manufacturing process parameters to minimize the warpage.



Warpage prediction after geometry compensation in Digimat-AM. Left: Superposition of the as-printed (red) and as-design

**Optimize the manufacturing process**  
Quickly explore at virtually zero marginal cost the sensitivity of process parameters on the process quality and part fidelity

### Work with an efficient and user-friendly GUI

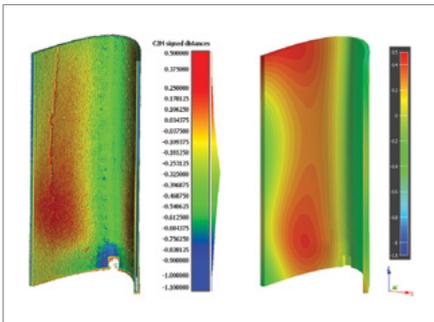
Designed to follow the printing workflow and accessible for non FEA experts

### Results/Correlation to Test Data

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



**Scott Sevcik,**  
Head of Aerospace,  
Defense & Automotive,  
Stratasys



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

### Results/Benefits

Working with Digimat AM, Stratasys Engineers were able to:

#### Print it right the first time

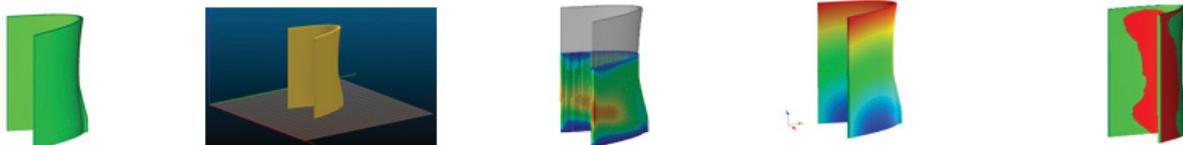
Iterate designs and parameters through simulation rather than wasting time and materials with iterating through printing

#### Save time & material

Anticipate printing issue with simulation (e.g., evaluate the impact of the printing direction and location on results)

#### Minimize warpage in only two steps!

Thanks to a predeformed geometry



**Iterate Virtual Printing Process with Counter-Warped Shape**



# Industrial 3D Printing Helps Develop A Better Race Car



by **Dr. Enrique Escobar de Obaldia**, Project Manager, Simufact  
**Dr. Patrick Mehmert**, Project Manager, Simufact  
**Dr. Hendrik Schafstall**, CTO, Simufact  
**Jan-Peter Derrer**, Product/Sales Manager, Renishaw

There is an ongoing development in the automotive industry of enhancing vehicles with more robust and powerful engines for more agile movements. In addition to engine power or traction control, the weight of the vehicle also makes a significant contribution to the performance on the track. An [SAE Formula Student](#) team, The GreenTeam in Stuttgart, Germany, reached out to [Renishaw](#) to support them in achieving this task for their electric racing car. While the GreenTeam was working on the redesign of the wheel carrier, which was originally made of aluminum, they tried in vain to find a sponsor who would be able to make the improved wheel carrier design. These problems arose because optimizing the weight and force parameters would result in component features (e.g. cavities), which

are difficult to achieve with conventional manufacturing methods especially with titanium, since it is notoriously difficult to machine. With its metal powder-based additive manufacturing system, the British engineering technology company Renishaw was able to meet these requirements. Renishaw is one of the world leaders in the field of metal additive manufacturing. It is the only UK based business that designs and makes industrial machines capable of printing parts from metal powder.

However, accurately addressing such a complex geometry is quite challenging. Renishaw solution center in Germany turned to Simufact Engineering Additive Manufacturing solution, [Simufact Additive](#), as their tool of choice to optimize the manufacturing with the goal of reducing the high distortion of the part and the separation of the support structures.

## Challenge

AM is a novel method for manufacturing complex lightweight parts from 3D models, where traditional methods might increase costs through tooling or longer production times. Although, Additive Manufacturing has been used for many decades, it began catching the attention of the automotive industry in recent years.

Between the metal based powder approaches, a powder bed fusion machine from Renishaw was used to print the wheel carrier of the formula student car. The laser machine fuses selected regions of a powder bed. Once a layer has been scanned and the selected material is melted, a new layer is then deposited. It is similar to other thermal analysis processes where many process parameters are influencing the quality of the printed part (i.e. build speed, power source, layer thickness).

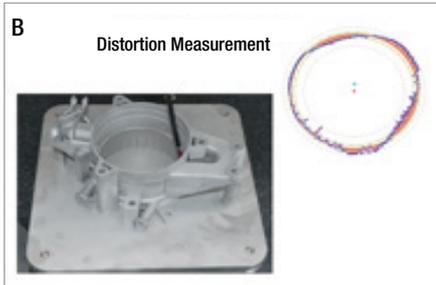


Fig.1: Printed wheel carrier. A- separation observed in the support structure, B- Measurement of the distortion at the top of the part

Controlling the process parameters represents a challenge - even multiple tests do not necessarily lead to optimal settings. Therefore, it is common to print parts out of tolerance or with visible damage. In the case of the wheel carrier, Renishaw's engineers observed cracks at the interface between the part/baseplate and the part/support (figure 1A). In addition, a scan performed at the top of the part showed an undesired distortion (figure 1B).

Renishaw needed a simulation solution to enable their design team to not only optimize the design for a lighter weighted vehicle, but also for a "first-time-right" printed part. This leads to much higher productivity and helps to eliminate high costs. Process simulation has become a well-established method due to its

increasing precision and reliability of simulation results, shorter and more practical calculation times, and improved usability of the simulation software. Renishaw therefore contacted Simufact Engineering, known simulation experts in manufacturing technology, to predict the build process and eliminate any distortions or separations of the support structures.

### Solution

Simufact Engineering's software tool, Simufact Additive, offers a macro scale approach that can be used to optimize not only the stage where the part is built, but also the subsequent process chain. The macro analysis considers the inherent strains that are induced by the manufacturing process. These inherent strains comprise plastic, thermal, creep and phase transformation strains. In Simufact Additive, the inherent strains can be easily calibrated with a calibration module.

To calibrate the inherent strains, Renishaw printed two cantilever samples at 0° and 90° of orientation with the same machine parameters used to print the part. The material used for the calibration (TiAl6V4 powder) is part of Simufact Additive's material database. After printing was completed, the cantilevers were cut in the middle of the toothed section (height = 3mm) and the distortion was measured. The cantilevers were not completely removed from the baseplate to maintain a reference point and prevent rigid body motion. The displacement measured in each cantilever was then used to calibrate the inherent strains. After 7 simulations, the calibration reached the target distortion (figure 2) with a maximum acceptable deviation of 0.3%.

The next step was to simulate the part with the calibrated inherent

strains. To overcome the limitation of meshing complicated parts and (due to the similarity with the layer by layer manufacturing process), Simufact Additive uses a voxel mesh of cubic shape. The voxel elements represent several layers of powder material that are sequentially activated. In the analysis, the support structures were imported from a CAD file and modeled with the same titanium alloy used in the part. The part and supports were placed on a baseplate, and modeled with 82 layers of voxel elements of 0.06 mm of powder layer thickness. A voxel element size of 1 mm was used to discretize the components (part, supports and baseplate), where every element consisted of around 17 powder layers.

The second stage of the project was to evaluate the accuracy of the simulation results. Renishaw's engineers measured the distortion at three locations of the part. The predicted distortion correlated positively to physical testing (figure 3). Even more, the cracks observed by Renishaw's engineers in the wheel carrier were also predicted in the simulation results (figure 4A). After further analysis, the Renishaw team concluded that the regions with high maximum principal stresses that led to failure after printing the part. Finally, the shape of the part in figure 1B can be compared with the simulation result in figure 4B.

*Continued...>>*

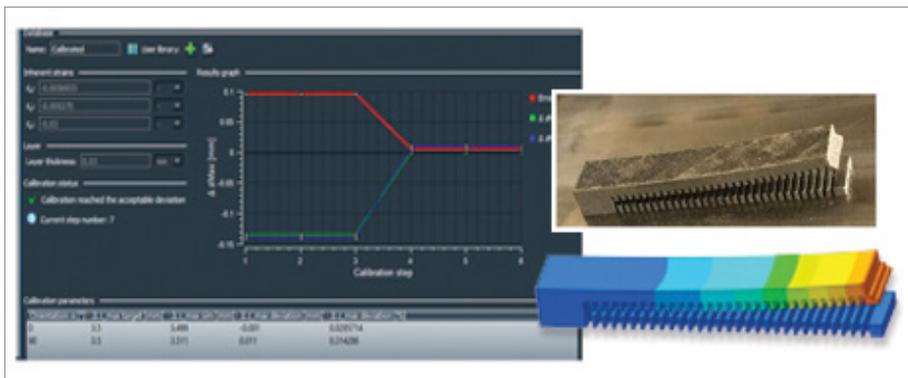


Figure 2: Calibration of inherent strains

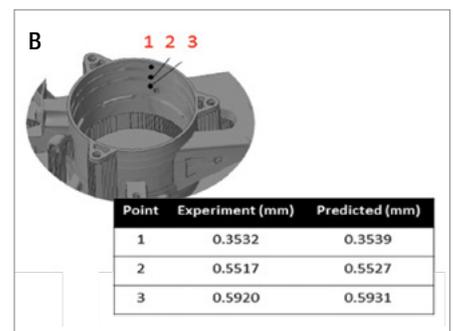
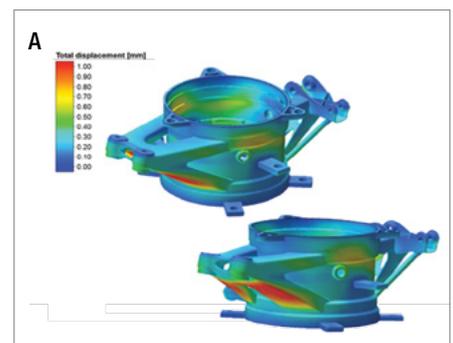


Figure 3. A- distortion, B- Comparison between experimental and predicted distortion

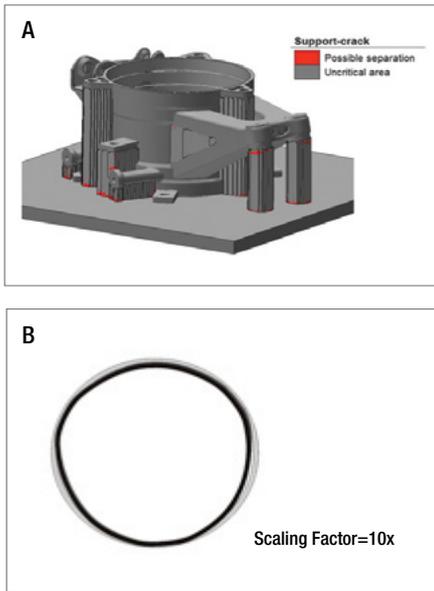


Figure 4: Simulation results with calibrated inherent strains. A- fracture areas, B- Shape of the part with scaling factor 10x

### Results

To compensate for the distortion observed in the inner region, a new design was proposed. Four inserts were added to the part and a new support structure was created with Simufact Additive (figure 5A). Compared with figure 3A, the new results in Figure 5C illustrate that the localized distortion was reduced in all regions.

The inner section was also predicted to maintain its cylindrical shape (figure 5B). Figure 5D shows that the distortion was reduced with respect to the original configuration. Although a new design had been proposed, other changes can be easily analyzed with Simufact Additive, such as the use of distortion compensating designs based on pre-distortion or changes in the process chain. ♦



**Simufact Additive offers a macro scale approach that can be used to optimize not only the stage where the part is built, but also the subsequent process chain.**

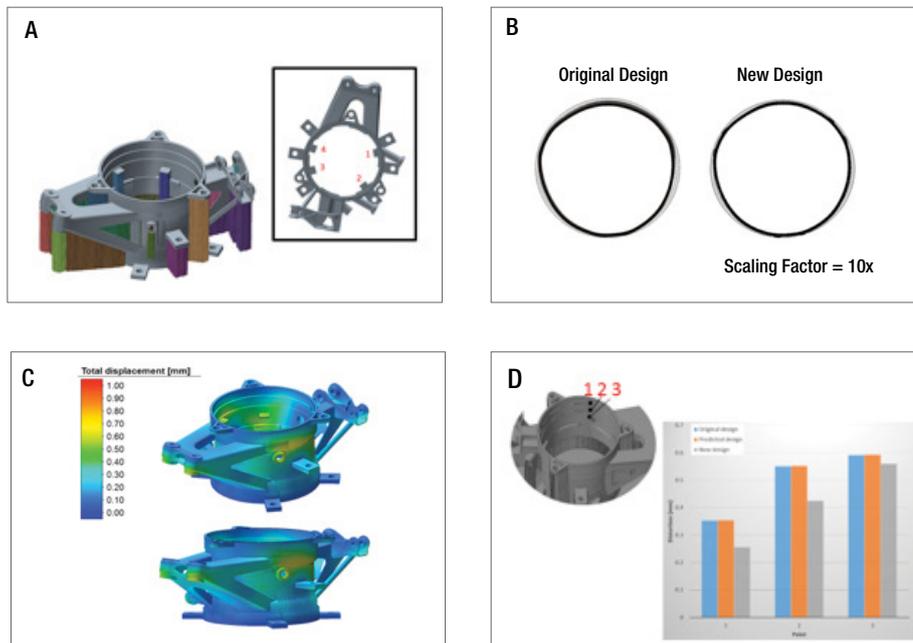


Figure 5: Simulation results of optimized part. A- New design, B- Distortion, C- Shape of the part with scaling factor 10x, D- Comparison of distortion values

### About Renishaw

Renishaw is a world leader in the field of additive manufacturing (also referred to as metal 3D printing), where it is the only UK business that designs and makes industrial machines, which 'print' parts from metal powder. The majority of Renishaw's research and development and manufacturing is carried out in the UK. The Renishaw Group currently has more than 70 offices in 35 countries, with around 4,000 employees worldwide. Around 2,600 people are employed within the UK where the company carries out the majority of its research and development and its manufacturing.

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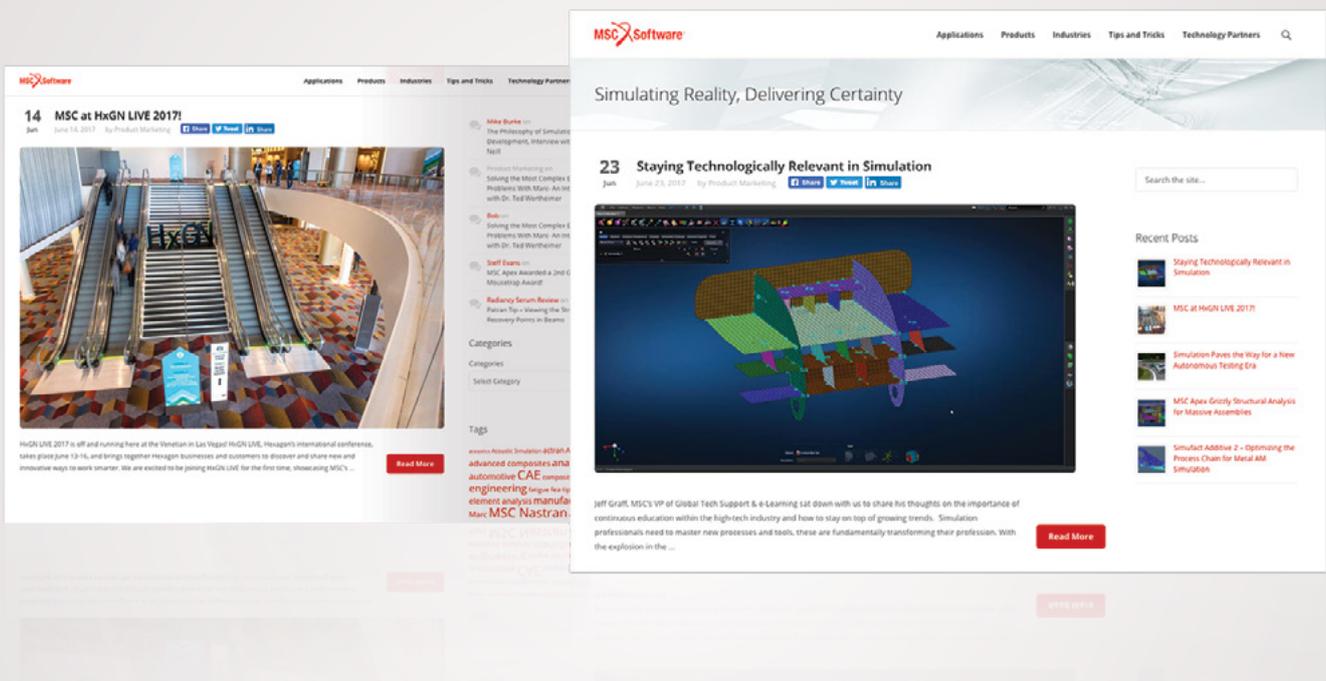
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