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Henrique A. Almeida · Joel C. Vasco
Editors

Progress in Digital and Physical Manufacturing

Proceedings of ProDPM'19

Springer

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Preface

The “Progress in Digital and Physical Manufacturing” book contains keynotes and papers presented at the first International Conference on Progress in Digital and Physical Manufacturing (ProDPM’19), organized by the School of Technology and Management (ESTG) of the Polytechnic Institute of Leiria (IPLeiria), from October 2 to 4, 2019.

This international conference aims to provide a major international forum for the scientific exchange of multi-disciplinary and inter-organizational aspects performed by academics, researchers, and industrial partners in order to exchange ideas in the field of digital and physical manufacturing and related areas. It represents a significant contribution to the current advances in industrial digital and physical manufacturing issues as it contains topical research in this field.

The ProDPM’19 conference expects to foster networking and collaboration among participants to advance the knowledge and identify major trends in the field. The conference addresses to industrial challenges focused on current market demands and actual technological trends, such as mass customization, new business, and industrial models or predictive engineering. Its contribution in science and technology developments leads to more suitable, effective, and efficient products, materials, and processes, generating added value for the industry and promoting the awareness of the role and importance of the digital and physical manufacturing development in the society.

This book is, therefore, an essential reading for all of those working on digital and physical manufacturing, promoting better links between the academia and the industry. The conference papers will cover a wide range of important topics like additive manufacturing, biomanufacturing, advanced and smart manufacturing technologies, rapid tooling, micro-fabrication, virtual environments, simulation and 3D CAD and data acquisition, materials, and collaborative design.

We are deeply grateful to the keynote speakers, authors, participants, reviewers, the International Scientific Committee, session chairs, student helpers and administrative assistants, for contributing to the success of this conference.

Henrique Almeida
Joel Vasco
Conference Co-chairs

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Conference Co-chairs

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Invited Lectures

The conference had the privilege of including in the scientific program the following world-renown speakers:

Alain Bernard, École Centrale de Nantes, France

Prof. Alain Bernard, 1960, graduated in 1982, PhD in 1989, was Associate Professor, from 1990 to 1996 in Centrale Paris. In 1996, he got Full Professor position in University Nancy I, in the "Integrated Design and Manufacturing" team, and moved to Centrale Nantes in 2001 where he was Dean for Research (2007–2012). He is Researcher in Digital Sciences Laboratory (LS2N-UMR CNRS 6004) in the "Systems Engineering" (IS3P) team. Recent research topics are KBE applied to computer-aided decision-making systems for additive manufacturing. He is Vice-President of the French Additive Manufacturing Association (AFPR), CIRP Fellow and Member of the French National Academy of Technologies.

Bruno Romero, HP Inc.

Bruno Romero is the Iberia 3D Printing Applications Engineer of HP's 3D Printing Jet Fusion Business. This position includes supporting Spain and Portugal sales team and transferring HP's 3D Printing knowledge to partners and customers. Main team is based in Barcelona, Spain. Bruno joined HP in 2017 in the 3D Printing Sales organization and Applications Development team. In this position he is connected to Business Development, Sales, Marketing and R&D teams but also to the WW Applications Development team.

Carlos Mougueira, TRUMPF, Portugal

Carlos Mougueira has been Employee at TRUMPF Portugal since 2015 as Sales Engineer responsible for Laser Division in Aerospace, Automotive and Metalworking sectors. He graduated in Mechatronic Engineering from Universidade de Évora and has gained experience in Laser Technology and Systems in Portuguese and Spanish industries during more than 10 years.

Eujin Pei, Brunel University London, UK

Dr. Eujin Pei is Director for Postgraduate Research and Program Director for the BSc Product Design and BSc Product Design Engineering programs at Brunel University London. He is a Chartered Engineer (CEng) and a Technological Product Designer (CTPD) with the Institution of Engineering Designers. He is Convenor of the International Organization for Standardization ISO/TC261/WG4 committee that is responsible for Data Transfer and Design Standards for Additive Manufacturing and Chair for the British Standards Institute BSI/AMT/008 for Additive Manufacturing. His research interest centers on functionally graded additive manufacturing and 4D printing.

Igor Drstvensek, University of Maribor, Slovenia

Prof. Dr. Igor Drstvensek is Lecturer at University of Maribor, Faculty of Mechanical Engineering, where he is lecturing production technologies and maintenance. His research work in the last 15 years is dedicated to additive manufacturing and especially to medical applications of Additive Manufacturing. He is Head of the Additive Manufacturing Laboratory at the Faculty of Mechanical Engineering, University of Maribor. In 2006, he has initiated the first implant production by the use of layered technologies in Slovenia and in last 10 years conducted 30 projects of cranial and maxillofacial implant production that ended with successful implantation of 27 PMMA and 3 Ti64 implants, owning several patent applications.

Inma Vazquez, Stratasys

Inma Vazquez is Channel Manager France and Iberia for Stratasys. She is one of the European women with more experience in additive manufacturing. Worked 11 years in 3DSystems, 2 years in HP division 3Dprinting and 4 years in Stratasys as Sales Manager. Speaks 6 languages and is an expert in introducing new products in several European markets focusing on applications to improve manufacturing processes in various industries.

Jaume Homs, HP Inc., Spain

Jaume Homs is the Iberia Channel and Sales Manager of HP's 3D Multi-Jet Fusion Business. This position includes Spanish and Portugal responsibility of channel recruitment, management, and sales of HP's 3D Printing Multi-Jet Fusion line of solutions. Main team is based in Barcelona, Spain. He joined HP in 2002 in the R&D organization as Software Engineer and Project Manager. Since then, he has held different positions in R&D, marketing, sales, and business management. Prior to his current position, he was the Indigo Commercial Business Manager for Europe Middle East and Africa. Previously, he had a sales position in Iberia in the Indigo business and prior to that in the DesignJet business. He has a proven track over-achieving all business goals. He holds a Master in Computer Science from

Universitat Autònoma de Barcelona, a Master in IT Management, and an Executive MBA by la Salle.

Joana de Medina, Stratasys

Joana Mayeur de Medina is a Chemical Engineer with over 20 years' experience in technical sales and key account management. Born in Rio de Janeiro, Joana has moved to France in 2001 and has built a successful career growing businesses at different levels for companies such as ExxonMobil, Xerox, Canon, Experian and HP. In 2016, Joana has embraced the challenge of building up the 3D printing business for HP in France. Since 2018 at Stratasys, she is the Strategic Account Manager for France and Iberia, working actively with the main industries to develop and implement additive manufacturing solutions that will transform the Industry.

Omar Fergani, Siemens, Germany

Dr. Fergani is Strategic Software Technology Manager at Siemens digital industries software. His main focus is to deliver cutting-edge software technology to industrialize additive manufacturing (AM). Some of his topics of interest are print first-time-right processes, the closed-loop solution to achieve the autonomous machines as well as the smart factory. Previously, he oversaw developing the first AM process simulation to complete Siemens digital twin offering. He is a holder of a Ph.D. in mechanical engineering and a double master's degree in manufacturing and materials from the Georgia Institute of Technology and the Norwegian University of Science and Technology. He is selected as one of the outstanding young manufacturing engineers and was previously selected as 30 under 30, future leaders of manufacturing by the Society of Manufacturing Engineers.

Paulo Bártolo, University of Manchester, UK

Paulo Bártolo is Professor of Advanced Manufacturing and Head of the Manufacturing Group at the School of Mechanical, Aerospace and Civil Engineering, University of Manchester. He is the University's Industry 4.0 Academic Lead, Team Leader of the Industry 4.0 societal challenge at Digital Futures, and sits on the Management Board of the EPSRC & MRC Centre for Doctoral Training in Regenerative Medicine. He is Professor at the Advanced Manufacturing Group at the Tecnologico de Monterrey, at Nanyang University, and Member of CIAUD (at University of Lisbon). He is Fellow of CIRP, Advisor of the Brazilian Institute of Biofabrication and several UK and International Funding Agencies, and received a commendation and pubic recognition from the Portuguese Government. He is Founding Editor of Virtual and Physical Prototyping Journal and Editor-in-Chief of Biomanufacturing Reviews.

Terry Wohlers, Wohlers Associates Inc., USA

Terry Wohlers is President of Wohlers Associates, Inc., an independent consulting firm he founded 32 years ago. He has authored more than 421 books, articles, and technical papers on product development and manufacturing and has given 155 keynote presentations on five continents. In 2004, he received an Honorary Doctoral Degree of Mechanical Engineering from Central University of Technology in Bloemfontein, South Africa. In 2005, he became Fellow of the Society of Manufacturing Engineers (SME). In 2016, he became Adjunct Professor at RMIT University in Melbourne, Australia. For 24 years, he has been Principal Author of the Wohlers Report, an annual worldwide publication focused on additive manufacturing and 3D printing.

Ulric Ljungblad, Freemelt

Dr. Ulric Ljungblad is CEO and co-founder of Freemelt. After his PhD at University of Gothenburg, he worked for 10 years in the semiconductor industry. From 2006 he has been working in additive manufacturing focusing on systems development and innovation. He holds more than 20 patents. He co-founded Freemelt in 2017 aiming to launch an open source electron beam AM system to promote much faster devolvement of processing parameters for new metal materials. He worked as R&D manager at Freemelt during the development of the Freemelt ONE system that was launched in 2018 and he became the CEO of Freemelt in 2019.

Keynotes

HP 3D Printing: Accuracy and Repeatability in Digital Manufacturing

Bruno Romero Azorin

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Abstract. HP Multi Jet Fusion it is a 3D Printing technology with a high rate of penetration into real manufacturing environments. This aspect is pushing HP to deliver products and solutions more robust, more profitable, with higher productivity, and more precise and accurate. Recently, HP has introduced the new printer Jet Fusion 5200 and the software HP 3D Process Control that will allow to produce high volume of parts at the lowest cost and with tolerances matching ISO 286 IT13 grade and repeatability with Cp CpK over 1.

Keywords: Multi Jet Fusion · Additive Manufacturing · Process capacity · OEE

1 Process Capacity and OEE in Digital Manufacturing

1.1 HP Multi Jet Fusion Approach to Process Capacity and OEE

Nowadays there are many 3D Printing technologies available in the market. Each technology presents advantages for certain applications, namely, prototyping, jigs and fixtures or tooling and in some cases true final parts. However, manufacturing final parts in big volumes with consistency, repeatability, part quality and cost effectiveness it is only available for few technologies.

HP's Multi Jet Fusion (MJF), first introduced in 2016, is a technology ready for manufacturing environments capable to compete with plastic injection molding and CNC machining in terms of material properties and isotropy, cost per part and productivity. The factors that increase the breakeven point of MJF vs. injection molding or CNC machining are part size, part design complexity and expected production volume. For instance, a gear of 30 cm3 up to 100,000 units it would be more economic to be manufactured using MJF than with injection molding (Fig. 1). The first HP 3D Printer, Jet Fusion 4200, has proofed the big penetration in several markets and in many of the cases to produce true final parts.

Recently HP has introduced a new MJF platform: the HP Jet Fusion 5200. The hardware architecture and several software modules of this 3D Printer have been designed to maximize the accuracy and repeatability of printed parts, while increasing the OEE (overall equipment effectiveness).

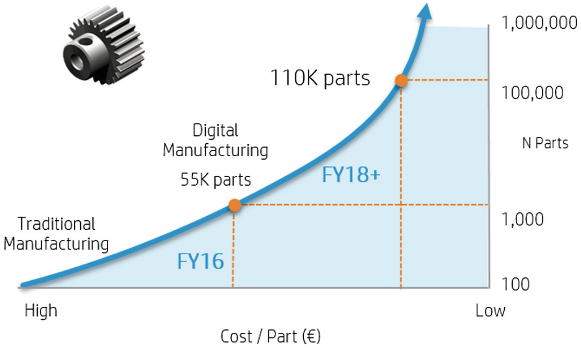

Fig. 1. Cost per Part breakeven point MJF vs. Injection Molding.

In terms of accuracy and repeatability, most of the printers in the market make trade-offs in mechanical properties and achievable dimensional tolerances depending on part orientation, part location on the build platform resulting in low process capacity (Cp and CpK). Thanks to the software HP 3D Process Control and complex algorithms running from HP's Cloud System, the users are able to create parts with consistent dimensions and tolerances independently of the build location and build after build achieving high process capacity (Cp and CpK).

The OEE is a metric that integrates the tracking and control of the entire end-to-end manufacturing process, enabling the detection of deviations that might appear at any stage of the process. The HP 3D Printers are designed to bring the highest OEE among the printers in the market.

1.2 HP 3D Process Control

HP 3D Process Control it is a cloud-based software developed by HP that will allow to print parts consistently with a tolerance in the range of grade IT13- IT14 according to ISO 286 (Fig. 2).

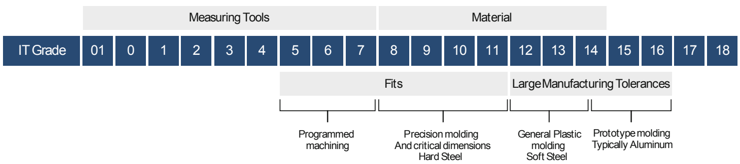

Fig. 2. ISO 286 IT grades description.

Conversationally IT13-IT14 grades are well known tolerance ranges achievable by injection molding with aluminum molds and soft steel molds (Fig. 3).

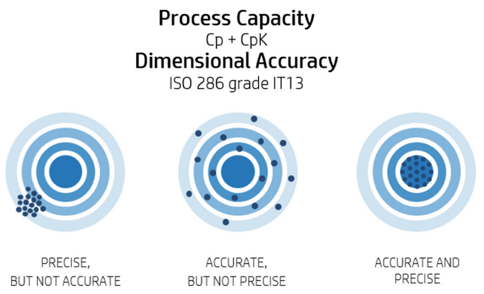

Fig. 3. Visual description of Precision and Accuracy.

Additionally, HP 3D Process Control enables dimensions consistency across the build and build after build by defining a Cp/CpK for a given set of critical dimensions in a given part.

Basically, 3D Process Control operates creating a profile of the build platform compensating the dissimilar material contractions all over the build volume acting at several levels:

- MJF technology singularities and aspects
- Printer by printer deviations
- Part by part geometry singularities

1.3 Overall Equipment Effectiveness

The OEE is calculated by multiplying the manufacturing process availability, quality and performance (Fig. 4).

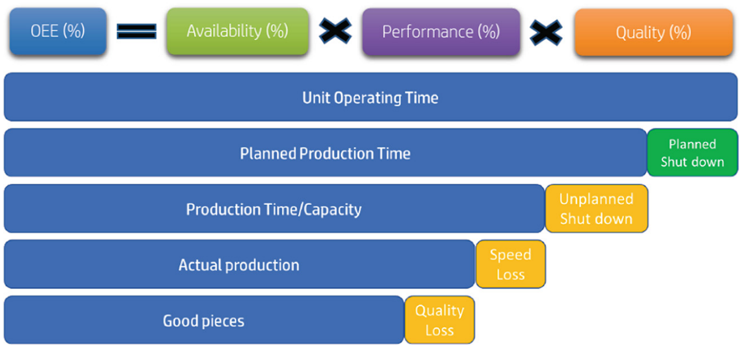

Fig. 4. OEE (overall equipment effectiveness) definition.

Availability factor refers to unexpected waiting times. HP strategy to maximize this factor is:

- 3D Printers are designed modular to maximize the operability and throughput;
- Printer components and systems are tested to determine end of life and to proactively suggest predictive maintenance;
- Components known to fail in a higher rate are redundant to avoid stops during manufacturing process;
- Basic HP Service Support includes remote support and next business day on-site support.

Performance factor refers to deviations to expected process time. HP strategy to maximize this factor is:

- 3D Printers are designed modular to maximize the operability and throughput;
- The printing module does several subsystems pre-checks and calibration before starting the printing process. These operations are most of the parallel to shorten the time. Once the print is finished the build platform can be extracted and the printer immediately ready to print a new build.

Quality refers to parts that are out of specifications, mainly in dimensions. HP strategy to maximize this factor is:

- Define a clear expectation of achievable dimensional tolerances according to ISO 286;
- Provide and adjust repeatability and accuracy thanks to HP Process Control;
- Thanks to HP Service Support react to any deviations to help customers to get back to quality parameters.

Laser Metal Deposition and Laser Metal Fusion

Carlos Mougueira

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Abstract. Additive Manufacturing: the benefits of the Laser Metal Fusion and Laser Metal deposition in application areas where conventional production reaches its limits.

Keywords: Additive Manufacturing · 3D Printing · Laser Metal Fusion

1 Additive Manufacturing Process

1.1 Laser Metal Fusion

Powder Bed Based laser melting (Laser Metal Fusion, LMF) is often referred to as metallic 3D printing, Powder Bed Fusion or Selective Laser Melting. The laser builds up the workpiece layer by layer from a bed of powder. The blueprint is provided by a CAD model. Tools are not required. The powder is applied to a platform, and the laser beam melts the powder with high precision, according to the CAD data, connecting defined locations with the layer below. The laser then repeats this process until the metallic component is ready. The workpiece now possesses the properties of the material that was used in powder form. A large number of metallic materials in powder form can be used for this method, including steel, aluminum, or titanium (Figs. 1 and 2).

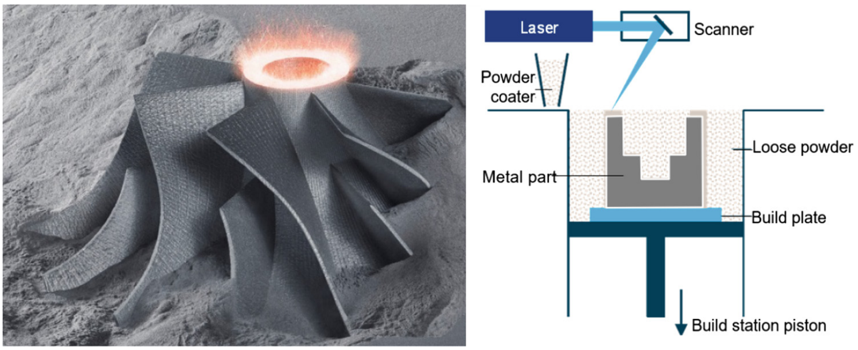

Fig. 1. Powder Bed Based laser melting (Laser Metal Fusion, LMF).

Example: Exhaust Manifold:

- Material: Titanium
- Nº of layers: 2 915 | 60 µm
- Time of processing: 26 h 33 min
- Objective: Design optimization

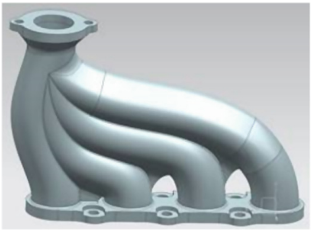

Fig. 2. Optimization design of a manifold.

1.2 Laser Metal Deposition

Laser Metal Deposition – or LMD for short – is also known as Direct Energy Deposition or Laser Cladding. The process is simple to explain. The laser creates a melt pool on the surface of the component, and metallic powder is automatically fed in through a nozzle. Interconnected weld beads are thus formed which form structures on existing substrates or even create entire components (Fig. 3).

Example: Wishbone

- Material: Aluminum
- Time of processing: aprox. 20s
- Objective: costs and time production reduction

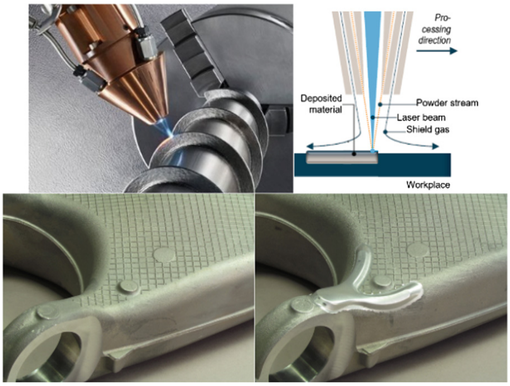

Fig. 3. Laser metal deposition on a wishbone component.

Reference

1. TRUMPF Laser-und Systemtechnik GmbH

Digital Manufacturing Is a Reality with HP 3D Printing: Introducing the New HP 3D Jet Fusion 5200 Printing Solution

Jaume Homs

Sales Manager HP 3D Print Iberia
HP Inc., Sant Cugat, 08174 Barcelona, Spain
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Abstract. HP Multi Jet Fusion it is a 3D Printing technology with a high rate of penetration into real manufacturing environments. This aspect is pushing HP to deliver products and solutions more robust, more profitable, with higher productivity, and more precise and accurate. Recently, HP has introduced the new printer Jet Fusion 5200 and the software HP 3D Process Control that will allow to produce high volume of parts at the lowest cost and with tolerances matching ISO 286 IT13 grade and repeatability with Cp CpK over 1.

Keywords: Multi Jet Fusion · Additive Manufacturing · Mass production

1 Unleash New Growth and Scale Production with HP's Most Advanced Plastics 3D Printing Solution

1.1 Introducing the New HP 3D Jet Fusion 5200 Printing Solution

HP has recently announced the release of its new Jet Fusion 5200 Series 3D printing solution, introduced a new TPU material, launched its Digital Manufacturing Network and expanded on strategic partnerships within various industries.

The major announcements broaden the company's AM operations in a big way and enable HP customers to truly exploit digital manufacturing. As Christoph Schell, President of 3D Printing and Digital Manufacturing at HP, explained: "*The Fourth Industrial Revolution is one of the most transformative forces in our lifetime. New technology innovations will be required, new partnership models will emerge and new modes of doing business will unfold*".

HP is committed to helping customers with diverse manufacturing needs turn change into opportunity by delivering the most innovative solutions portfolio and comprehensive ecosystem of industry-leading partners. The broadening of our portfolio with the new Jet Fusion 5200 Series 3D printing system, coupled with expanded industrial alliances and our new Digital Manufacturing network, are important accelerators of our digital manufacturing journey.

The new Jet Fusion 5200 Series expands upon HP's existing Multi Jet Fusion portfolio, which also includes the Jet Fusion 300/500 Series for functional prototyping applications and the Jet Fusion 4200 Series, for short runs and production. The new 3D printer series adds to the portfolio, offering a solution for volume production.

The hardware comes with a number of improvements and upgrades which enable users to benefit from higher productivity, accuracy, consistency and efficiency. Other advantages of the new series include increased flexibility, improved uptime, streamlined workflows and simplified fleet management.

The new system effectively moves the center of the operation from a two-pass mode to a one-pass mode. This approach is enabled by the presence of a more powerful lamp and allows for a higher degree of productivity compared to HP's other MJF systems. Further, the more powerful lamp also creates opportunities for working with high-temperature materials down the line.

The Jet Fusion 5200 Series also integrates a more sophisticated thermal imaging system (with five times the resolution of the 4200 Series), providing better precision and tighter process control.

The new 3D printing system also comes with a new cooling module, which further streamlines and automates the production process. The low-cost cooling unit essentially sits on top of the build unit and once the printing process is complete, the still hot parts are automatically transferred into the cooling boxes so that the build unit is liberated for the next job. This is highly advantageous for customers requiring high productivity and that operate multiple build units.

The 5200 Series comprises of three 3D printer models: the Jet Fusion 5200, Jet Fusion 5210 and Jet Fusion 5210 Pro. The latter two models offer better economic value than the 5200 for larger volume production. The 5210 models are also more conducive for industrial applications because they enable manufacturers to see the status of the machine from a distance.

1.2 Improved Software and New Materials

To accompany the new hardware, HP has also introduced two new software suites: **3D Process Control** and **HP 3D Center**. The former helps to optimize the dimensional accuracy and consistency of part geometries. HP 3D Center, for its part, gives users the tools to optimize their whole factory. Finally, HP also launched the HP 3D Parts Assessment Service, which helps customers to identify and assess what parts can be 3D printed.

Excitingly, HP has also taken this opportunity to launch a new material for its Jet Fusion 5200 Series technology: **ULTRASINT**, a TPU thermoplastic polyurethane material developed by BASF. The new material is well suited for the automotive, industrial and consumer goods sectors for applications that require good shock absorbance, energy return and flexibility.

A number of companies are already utilizing the new material and HP's Jet Fusion 5200 systems for production applications (Fig. 1).

Fig. 1. HP 3D Jet Fusion 3D Printing Solution.

The Digital Twin of Production, the Ultimate Tool to Achieve First-Time-Right in Metal Additive Manufacturing

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Abstract. The concept of digital twin is at the core of the digital transformation happening in manufacturing industries. The digital twin of the production process is an effective technology that allows the use of data-driven or physics-based model to simulate the process and optimize the process parameters to achieve the best quality product. In the context of additive manufacturing, the scrap rate is high compared to more traditional process. Due to the full digital nature of AM processes, the concept of digital twin of the process, also referred to as the process simulation is used in this presentation as a test bed to demonstrate the usefulness of the digital twin of the production.

Keywords: Additive Manufacturing · Digital twin · Process simulation

1 Introduction

A digital twin is a virtual representation of a physical product or process, used to understand and predict the physical counterpart's performance characteristics. Digital twins are used throughout the product lifecycle to simulate, predict, and optimize the product and production system before investing in physical prototypes and assets. By incorporating multi-physics simulation, data analytics, and machine learning capabilities, digital twins are able to demonstrate the impact of design changes, usage scenarios, environmental conditions, and other endless variables – eliminating the need for physical prototypes, reducing development time, and improving quality of the finalized product or process. To ensure accurate modelling over the entire lifetime of a product or its production, digital twins use data from sensors installed on physical objects to determine the objects' real-time performance, operating conditions, and changes over time. Using this data, the digital twin evolves and continuously updates to reflect any change to the physical counterpart throughout the product lifecycle, creating a closed-loop of feedback in a virtual environment that enables companies to continuously optimize their products, production, and performance at minimal cost. The potential applications for a digital twin depend on what stage of the product lifecycle it models. Generally speaking, there are three types of digital twin – Product, Production, and Performance, which are explained below. The combination and integration of the three digital twins as they evolve together is known as the digital thread. The term "thread" is used because it is woven into, and brings together data from, all stages of the product and production lifecycles.

In the context of additive manufacturing, Fig. 1 demonstrate the capabilities encapsulated in each digital twin in one integrated solution. To support the end user, solve multiple challenges related to the industrialization of additive manufacturing. From a system level, the data integrity and consistency are key to deliver the highest quality product and the end to end platform is an answer to this challenge.

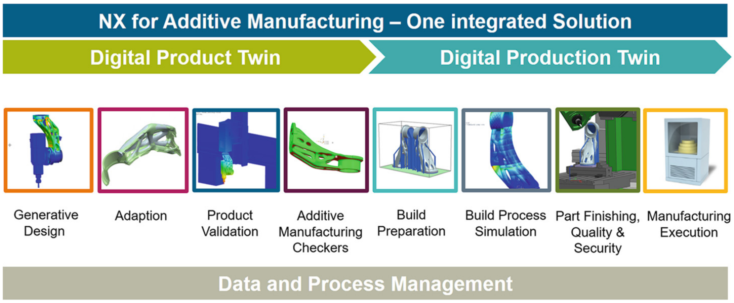

Fig. 1. Concept of the digital twin applied for additive manufacturing.

Moreover, the end to end solution deliver key technologies to solve other manufacturing issues such as the scrap rate. In additive manufacturing, and due to the complex thermos-mechanical process involved, the scrap rate is quite high (estimated at 30%) mainly due to challenges as described in Fig. 2.

Fig. 2. The different root causes leading to the high scrap rate in metal additive manufacturing.

As discussed previously, the concept of the digital twin provides multiple technologies integrated in one platform to address the most pressing manufacturing problems. In the next section, we will describe how the digital twin of the production process provides a strong physics-based tool to analyses the AM process at multiple level, from macro to micro scale identifying and correcting potential manufacturing challenges upfront in a cost-effective manner.

2 Methodology and Approach

The process simulation also digital twin of the manufacturing process provides a guided workflow to the user that allows for the assessment of distortions, the prediction of recoater collisions, prediction of areas of overheating, and other important feedback about the print process. The AM Process Simulation solution offers the ability to iterate on a solution between the design and build tray setup steps of the workflow, and the simulation step. This closed feedback loop is possible due to the tightly integrated nature of the CAD, CAM, CAE and the machine controller. The simulation data created feeds into the digital thread of information which informs each step of the printing process. This digital backbone enables the system to develop pre-compensated models and, more importantly, to feed those seamlessly back into the model design and manufacturing processes without additional data translation. This high level of integration is what customers need today in order to be successful in industrializing additive manufacturing.

Figure 3, describes the architecture of the finite element-based solution that was implemented for this purpose.

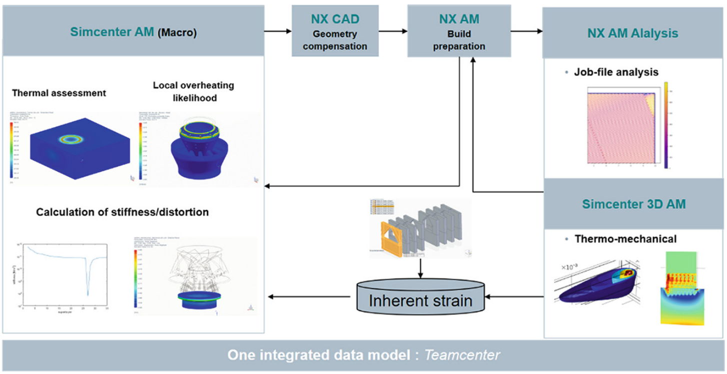

Fig. 3. Architecture of a finite element-based process simulation solution.

3 Results and Discussions

This technology was implemented and investigated in multiple use cases. We demonstrate here a complex gas turbine component. This part was designed thanks to additive manufacturing capabilities. The original part was an assembly of 27 parts that were consolidated to one in this case. The complexity of the geometry led to a number of manufacturing challenges. These issues were predicted thanks to the technology described previously and corrected upfront in a cost-effective way. Figure 4 describes the obtained results compared to the 3D scan.

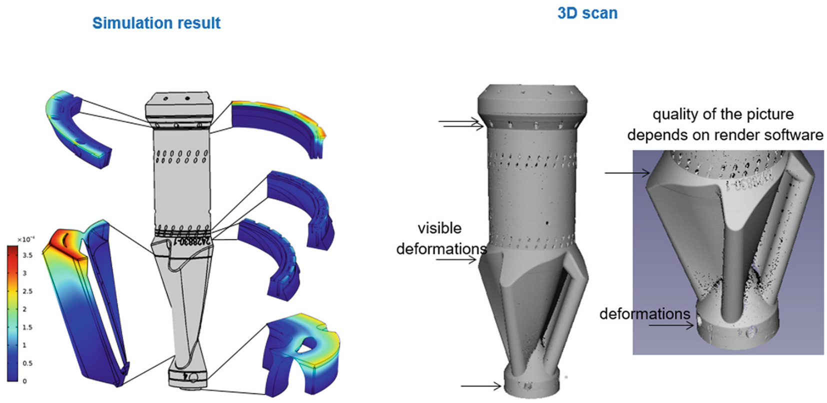

Fig. 4. Simulation results compared to 3D scans.

Multiple simulation demonstrated that the usage of the physics-based simulation to predict overheating, distortion and other challenges like residual stress is beneficial for the designer to make changes at an early stage. Also, it is demonstrated through experiments, that the process simulation is a key step to reduce machine failures, thanks to capabilities like prediction of recoater crash and the optimization of the job file. The ultimate objective of such technology is to achieve a zero scrap rate and deliver the promise of a fully digital manufacturing technology. Although the progress is impressive, efforts are needed to develop more technologies for additive manufacturing where the power of physics is combined with the insight from the data. Most of the future capabilities of Siemens digital twin will be based on this new paradigm.

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