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INTRODUCTION

The goal of MANUELA is the development and realization of a metal Additive Manufacturing (AM) pilot line service covering the full AM development cycle including simulation, robust AM manufacturing and on-line process control, characterization, real-time feedback, post-treatment, AM qualification protocols and associated business model.

MANUELA’s ambition is to provide the European industry with world class, reliable pilot line manufacturing service leveraging metal Additive Manufacturing products. This will be achieved by having the hardware solutions cost-efficiently connected to the best possible competences and capacities across Europe to cover the full range of powder bed fusion technologies from medium to large scale including Powder Bed Fusion Laser Beam (PBF-LB) as well as Powder Bed Fusion Electron Beam (PBF-EB) processes.

MANUELA is a project funded by European Union’s Horizon 2020 research and innovation program coordinated by Chalmers University of Technology, Sweden.
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The overall scope of Manuela is to facilitate a one entry contact to an independent and high level solution provision composed of a number of core AM laboratories and associated partners (see consortium overview). Through MANUELA project, the capacities are being developed and internal networks are being trained through R&D driven by a number of pre-defined use cases. Further validation of the pilot line will come after an open call for additional use cases will be opened to external companies. The MANUELA project involves all necessary capacities and competences to address the needs for development of solution for the fabrication and qualification of part by AM involving materials, design process and product assessment. The service is expected to allow companies across Europe closer and more rapid access to products/solutions they can bring to the market either in their own manufacturing or simply by commercial acquisition from service bureaus across Europe. MANUELA will provide the unique AM and will be able to assist further in the process, but the aim of the project is not to set up a commercial serial production entity of its own.
Additive manufacturing (AM) is an innovative and agile manufacturing method that adds material instead of subtracting it. There are some key advantages of AM compared with traditional manufacturing:

- **Innovative and flexible product design enabling complex geometries**
- **Optimized material utilization reducing waste generation**
- **Energy cost savings**
- **Reduced lead times**
- **Enhanced product differentiation**
KEY INNOVATIONS OF MANUELA

TAILORED RECYCLABLE METAL POWDER

PILOT LINE DASHBOARD

WORKFLOW OPTIMIZATION AND AUTOMATION

REAL-TIME PROCESS MONITORING

QUALIFICATION AND CERTIFICATION STANDARD

Pre-industrial testing for specific AM products

Full manufacturing chain available

Turn-key delivery/One-stop-shop

Time to market reduction

First-time-right product design

Qualified products for new segments

New materials integration into manufacturing line

'Green' technology approved by Life Cycle Analysis

Definition of AM guidelines

Advanced quality control process
USE CASES

The pilot line will be validated by these six use cases within which prototype components will be manufactured and demonstrated in their operational environment.

- HELMET MOUNTED DISPLAYS COMPONENTS FOR AEROSPACE APPLICATIONS
  - Time to market reduction: ~30%
  - Manufacturing cost reduction: ~25%
  - Product price reduction: ~20%
  - Production speed increase: ~30%
  - Market increase: ~20%

- NOVEL SLIP RINGS ALLOWING ENERGY AND SIGNAL TRANSFERS FOR ROTATING ACTUATORS
  - Time to market reduction: ~50%
  - Manufacturing cost reduction: ~40%
  - Product price reduction: ~30%
  - Production speed increase: ~30%
  - Market increase: ~20%

- CUSTOM-MADE CRANIAL IMPLANTS MADE OF TITANIUM ALLOY
  - Time to market reduction: ~30%
  - Manufacturing cost reduction: ~30%
  - Product price reduction: ~20%
  - Production of parts no longer available on market: ~50%
and technologies enabled by MANUELA

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
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<tbody>
<tr>
<td>~30%</td>
<td>Time to market reduction</td>
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<td>~40%</td>
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<td>~25%</td>
<td>Time to market reduction</td>
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<tr>
<td>~30%</td>
<td>Manufacturing cost reduction</td>
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<td>~20%</td>
<td>Subsequent machining reduction</td>
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<td>~30%</td>
<td>Production speed increase</td>
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<td>~25%</td>
<td>Increased turnover</td>
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<td>Time to market reduction</td>
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<td>~20%</td>
<td>Manufacturing cost reduction</td>
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POWER PLANT MACHINERY COMPONENTS (GAS TURBINE LINER AND INJECTOR) SUBJECTED TO HIGH THERMO-MECHANICAL STRESSES

ROCKER FOR MOTORSPORT COMPETITION

GAS TURBINE FUEL NOZZLE
HOW TO APPROACH THE PILOT LINE?

Chalmers Industriteknik (CIT) acts as single point of entry for the future customers to the MANUELA Pilot Line.

CHALMERS INDUSTRIEKNIK WILL PERFORM ALL FRONT ACTIVITIES INCLUDING MARKETING, CUSTOMER RELATIONSHIP, EVALUATION OF OPPORTUNITIES, REQUIREMENTS, OFFERS, MANAGEMENT AND SOURCING OF COMPLEMENTARY SERVICES, QUALITY CONTROL, INVOICING, AND CONTINUATION OF ECOSYSTEM BUILDING.

The Pilot Line will provide Open Access services according to the following flow:

In case you are interested to learn more about the MANUELA project or post-project operations, please contact:
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SERVICES – HARDWARE LAYER

Powder Bed Fusion – Laser Beam

**M290 medium-sized system**

Equipped with next generation quality monitoring systems for manufacturing of the component with focus on small to medium-size components with high requirements to the component quality and process robustness.

**M400 large system**

For AM fabrication of components requiring high manufacturing speed where in-situ quality assurance is not required.

MANUELA UTILIZES TWO PBF-LB SYSTEMS:
For PBF-LB, MANUELA’s concept is based on three main improvements:

1. **Optimization and Exploitation of the Advanced In-Situ Monitoring Systems to Improve Process Robustness**

   For a number of materials and applications, the build speed will be effectively increased by optimisation of processing parameters to achieve between 2-4 faster build cycle. Secondly, having the capability to monitor and control variation in the powder layer thickness at different built height in combination with respective exposure strategy (e.g. larger energy input in case of larger powder bed thickness) will allow also to tune build speed and build strategy to features and design needs without compromising requirements to the component and its functionality. Exploitation of the on-line quality assurance tools will allow to assure robustness of the PBF-LB process and hence minimize or totally avoid the need for expensive post-AM quality assurance. The process monitoring system at Chalmers involves three parallel systems for on-line acquisition and monitoring, powder-bed imaging, thermal imaging melt pool monitoring and optical tomography imaging providing input from laser-material interaction across the whole build.
The PBF-EB is particularly interesting to process high performance materials due to vacuum conditions and working temperatures of up to 1100°C. The electron beam consolidates the powder and in parallel heats the powder bed to maintain it at a pre-defined building temperature. The maximum beam power available in conventional EBM machines is about 3 kW and only used for maintaining the building temperature whereas powder consolidation works at much lower beam power. The MANUELA pilot line uses the EBM system Athene refurbished with a 6 kW electron beam gun and a new control system.

Typically, half of the building time is spent for powder bed preheating in order to maintain the processing temperature within the build tank. First tests with titanium demonstrate a possible strong reduction of the preheating time from originally 30s down to 7s, which nearly halves the layer fabrication time.

Thus, the process speed will be approximately doubled by using this new system with doubled power available.
SERVICES – HARDWARE LAYER

Post-AM processing with automated workflows

MANUELA WILL CREATE AN AGILE, SCALABLE, ROBUST, SAFE AND AUTOMATED WORKFLOW WHICH CAN BE TRANSFERRED TO BOTH SMALL AND LARGE-SCALE AM USERS. THE CONCEPT IS BASED ON USING THE EXISTING WORKSHOP ENVIRONMENT OF A USER, THUS REQUIRING MINIMUM NEAR FUTURE INVESTMENT TO IMPLEMENT AM. THE SOLUTION IS INTEROPERABLE TO BE ABLE TO SERVE MULTIPLE SYSTEMS INDEPENDENT OF AM MACHINE BRAND OR TYPE.

The post-processing for each build job and individual part will be set already in the design, optimization and preparation phase.

Automated Guided Vehicle will be used to remove and transport build jobs from the 3D printers to a pick-and-place station.

The post-treatment sequence of each build job and/or part is defined during the build job preparation.

Product and process data will be stored and tied to the unique ID of the part to allow traceability, analytics and feedback into the design/simulation platform of the pilot line.
SERVICES – HARDWARE LAYER

Quality monitoring

MANUELA CONCEPT RELIES ON THE DEVELOPMENT AND INTEGRATION OF THE STATE-OF-THE-ART ON-LINE QUALITY MONITORING SYSTEMS INTO THE PBF-LB AM PROCESS TO ASSURE CONTROLLED AM MANUFACTURING AND HENCE AVOID UNCONTROLLED DEFECTS, IMPROVE PROCESS ROBUSTNESS, STABILITY AND REPEATABILITY.

FOR PBF-EB, ELECTRON OPTICAL OBSERVATION WILL BE USED FOR THE DETECTION OF FUSION DEFECTS (TOO LOW ENERGY INPUT) OR MATERIAL HUMPING (TOO HIGH ENERGY INPUT) ALONG WITH MELT POOL MONITORING TO DETECT CRITICAL DEFECTS.

System Monitoring for records from system sensors that control platform heating, flow, laser power, temperature and also atmosphere to assure its constant composition and avoid or minimize contamination of the AM component by secondary phases as e.g. oxides or nitrides.

Powder bed monitoring for even and complete recoating of the building platform in each layer.

Process monitoring (camera-based OT and photodiode-based MeltPool) enabling real-time detection of overall process behaviour to minimize unpredictable microstructure defects. Identifying the most critical areas of the part and optimizing them in terms of process, part geometry and part position on the platform.
SERVICES – HARDWARE LAYER

Testing | Health & Safety

Hazards to operator health & safety will be minimized through automation of the entire process. An assessment and minimization through design and regular inspection of all possible dust generation areas of the pilot line will be done. The monitoring and control with respect to PM10 and PM2.5 will constitute important parts of the measures.
SERVICES – SOFTWARE LAYER

MANUELA Dashboard

THE DASHBOARD IS A COMPREHENSIVE, GRAPHICAL USER INTERFACE ENABLING EASY ACCESS TO THE PILOT LINE SOFTWARE CAPABILITIES

Digital world

MBSE System Software

Design & Engineering

Manufacturing

Metrology Software

Data Management and Analytics

Digital Mock-up

Supply chain

Real world

MANUFACTURING

Service Life

Supply chain

Metrology Hardware
Big data, data mining and machine learning

MACHINE LEARNING ALGORITHMS WILL BE APPLIED TO THE AM PROCESS IN ORDER TO ADAPT ITS PARAMETERS AND SUGGEST DESIGN CORRECTIONS CONSIDERING THE ENTIRE PILOT LINE PERFORMANCE OVER ITS LIFETIME.

Data mining of the big data will enable better understanding of obtained parts by identifying causal relations by means of clustering of all monitored parameters versus obtained part specifications.

Data is structured in an Engineering Lifecycle Management backbone so that it can be processed by Machine learning algorithms for decision.

Big data consists of various types of information, combining physical learning sets like in-line real time monitoring tools for instance optical imagery, and digital sets provided at a lower cost by multi-scale and multi physical simulation platforms.

Such data pond includes multiple types of parameters encompassing materials, process settings and signatures, or quality controlled information.
SERVICES – SOFTWARE LAYER

*Multi-scale and multi-physics simulation tools*

The simulation tools combining the big data with machine learning will include all relevant physics and apply them on multiple scales.

**Chemical | Mechanical | Optical | Plasma | Thermal**

- **Cellular solidification structure**
  - [1 μm scale]
- **Metal grains and melt pool size**
  - [100-500 μm]
- **Scale and part level**
  - [10-400 mm]

The combination of all simulation tools mimicking the entire pilot line is its digital twin, enabling digital iterations to achieve right-first-time manufacturing. This digital twin will be adaptive and will increase in efficiency proportional to the data acquired over the life of the pilot line.
SERVICES – SOFTWARE LAYER

Part design for efficient AM

The part design for efficient AM provides all relevant information enabling users to judge the feasibility and economic advantages of changing the manufacturing of a part or assembly of parts to an AM equivalent.

USER PROVIDES

- CAD FILE
- QUESTIONNAIRE
- ASSEMBLY INTERFACES
- APPLICATION SPECIFIC CONSTRAINTS

DATA MINING & MACHINE LEARNING

SIMULATION WORKFLOW

USER GETS

- MANUFACTURABILITY ANALYSIS
- PART SPECIFIC PROCESS FLOW
- PART OPTIMIZATION MINIMIZING DISTORTIONS AND WEIGHT
- SUPPORT STRUCTURES SUGGESTIONS

OPTIMIZATION TOOLS
A SELECTION OF 10 BUSINESS DEVELOPMENT CASES UTILIZING THE MANUELA OFFERING WILL BE MADE FOLLOWING AN OPEN CALL IN 2021.

**Implementation**
Project plan including user requirements, process flow charts, resource allocation and budgeting. All costs related to the project, such as process engineer hours, equipment time and consumables will be tracked and funded from MANUELA project.

**Proposal evaluation**
Identification of business development cases that address market needs using a novel approach that yields a step change, creates significant market value whilst enabling Europe to progress towards a resource-efficient economy and are competitively positioned to compete and succeed in the global Marketplace.

**Assessment and learning**
The business development cases will become the starting point for larger projects going towards mass manufactured AM products. Such trajectory will be guided by the pilot production service following the experience gained from running the use cases towards a trajectory outside MANUELA and into the pilot production service. Learnings from these cases will be incorporated in future pilot production services.
MANUELA
TEAM

Visit
www.manuela-project.eu
to learn more
about the project
and how to get involved.

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