# User Manual ESI-AM 2017

## MODULES

Document Version 2017-08-27

# 1. Contents

# 2. Introduction

ESI-AM integrates tools and solvers that resolve powder scale as well as component scale phenomenon. ESI-AM is this the first commercial integrated material engineering platform dedicated to metallic additive manufacturing. V2017 of ESI-AM focusses on Powder Bed Fusion (PBF) processes.


ESI-AM graphical user interface implicitly suggests a work flow supporting rapid low cost qualification of additive manufacturing processes and products.

ESI-AM nevertheless retains the flexibility that each tool can be used separately. It is not necessary to use the solvers in a certain sequence. Each tool can be run operated based on the data bases, experimental data or experience. This document describes ESI-AM numerical work flow and the modules utilized. The theory, assumptions and user manuals are available in separate documents.

# 3. Numerical Work Flow

The numerical work flow depicted below ensures the transfer of process relevant information across multiple length and time scales to assess different aspects of the additive manufacturing processes. The overall procedure is the foundation for simulation based qualification of the powder, process parameters and the work piece.

Prescan optimizes process parameters to achieve high material density and maximum build rate. Eligible process parameter combinations (pareto front) can be confirmed in subsequent steps. First spreading the powder of choice on the processing table is simulated to obtain the packing density as a function of table displacement. The packing density defines the maximum allowable vertical distortion during build. Should the distortion module indicate a higher distortion for a certain layer, interaction of the coater arm with the build can be expected. The user can then either exclude this set of parameters and choose the next combination from the pareto front, decide to use soft coater arm or optimize the support structure.

The work piece thermal history can be computed using the 3D printer control file. The outcome can be either used in a more accurate distortion and residual stress models or to assess the metallurgical evolution of the work piece. These options are currently in research mode and have not been fully integrated in ESI-AM.

The Distortion and Residual Stress module is used to confirm manufacturability, work piece orientation, support structure and to quantify final distortion and as-built residual stresses. The user can fine tune the outcome by choosing different processing parameters, changing orientation, deposition strategy or adapting the support structure utilized to stabilize the build.

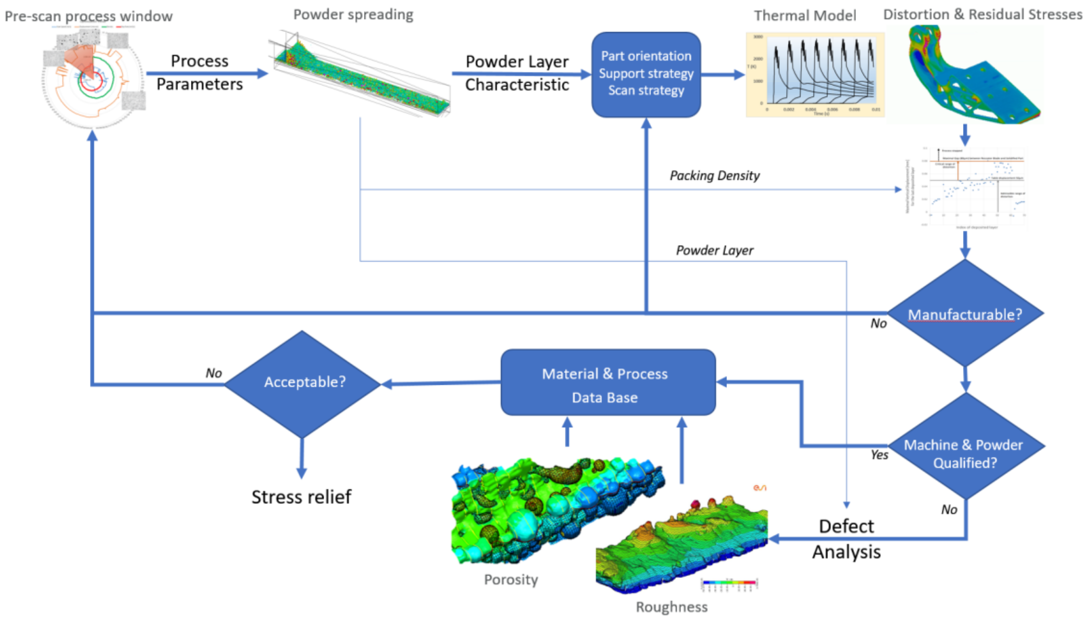



Figure 1: ESI-AM Integrated Computational Material Engineering for Additive Manufacturing

Once manufacturability and final distortion are confirmed to be acceptable, the material quality and the probability of build defects as well as surface finish can be assessed in melting module. The heat source powder interaction is resolved to simulation material melting, solidification and evaporation. The model is a three phase model resolving solid, liquid and gaseous phases allowing quantitative determination of porosity and surface roughness.

# 4. Modules

## 4.1. Data Base

ESI-AM modules require a lot of details about material behavior including data about phase changes (melting, evaporation), surface tension, optical behavior and material strength. Setting up models is much quicker when referencing the data base.

The data base, a repository of material properties, manages thermos-physical as well thermos-mechanical properties of metallic alloys. It includes template materials such as stainless steel 316L, Inconel 718 as Ti6Al4V. The contents can be used directly, they can be edited based on user experience or measurements and can be freely extended to include more materials.

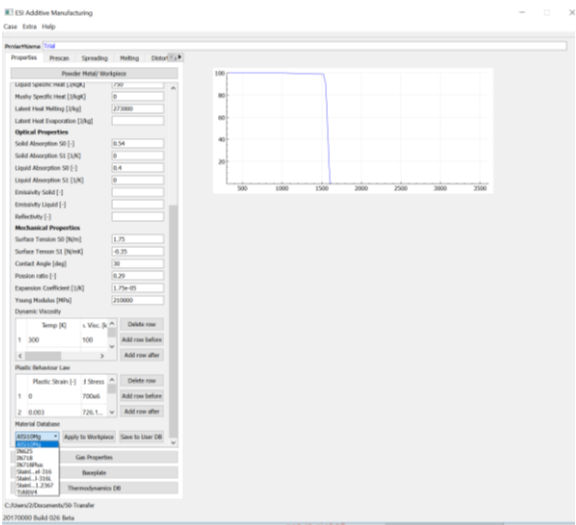


Figure 2: ESI-AM data base

It is important to note that material properties play a central role in prediction quality. It is therefore recommended to continuously revise and update the content based on supplier data sheets, new literature and new measurements.

The upcoming version of ESI-AM is to include additional information pertaining to powder, 3D printers and combinations of material – powder – printer and processing parameters. This solution will enable users to manage their printing knowledge and use it as a foundation for ESI-AM.

## 4.2. Prescan

The prescan module considers four process parameters: Power, scan speed, hatch spacing and table displacement when identifying a process window that enables printing of dense material at the highest possible build rate.

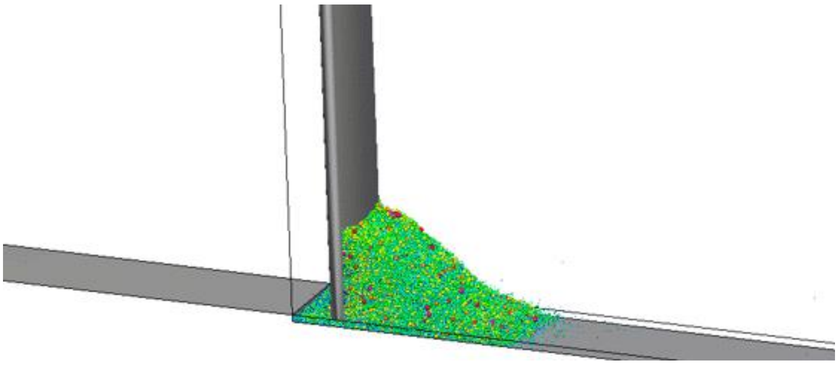
The model input include material properties, powder size distribution, bounds of printer performance (e.g. heat source powder ranges from 10 to 400 W). The multi-objective optimization problem delivers a pareto front of possible process parameter combinations that fulfil the optimization objectives.

The user can choose one of the points on the pareto front and proceed to qualifying the work piece and material quality achieved using more detailed analysis.

## 4.3. Powder Spreading

The powder size distribution and the table displacement are used to simulate the powder spreading process. The prototype assumes a rigid coater arm by default, but other geometries such as a roller can be defined in advanced mode.

Results are analyzed statistically to provide powder bed characteristics across the modelling processing table. Typical results include the powder packing density, change in powder size distribution and the geometric distribution of powder particles in the powder bed.



Using the packing density material consolidation and the space available above the processed material can be estimated. This information is used in the distortion module to assess manufacturability. Assessing the powder size distribution on the processing table enables assessment of powder recyclability as a function of the process parameters investigated. The powder bed geometry is utilized in melting models to resolve the heat source interaction with the powder and quantify as-built material quality.

## 4.4. Distortion & Residual Stress

The Distortion and Residual Stress module operates at work piece length scale. It automatically creates a computational grid, set suitable clamping conditions for the base plate and supports component analysis during build, at the end of the build process, release of the build plate from the machine and cutting the work piece from the base plate.

Input includes the CAD model, the support structure if defined and deposition strategy.

Both simplified and detailed modelling are supported allowing the use the flexibility of running quick trend analysis as well as quantitative analysis resolving deposition strategy. The elastoplastic material behavior is considered.

During the build process manufacturability is assessed by comparing the maximum vertical distortion of each layer with the space between build surface and coater arm predicted by the Spreading module.
If the support structure is not provided, the tool will create supports based on part orientation.
The final work piece shape and as-built residual stresses are calculated for different stages: End of build, release or base plate and cut off of work piece from base plate.

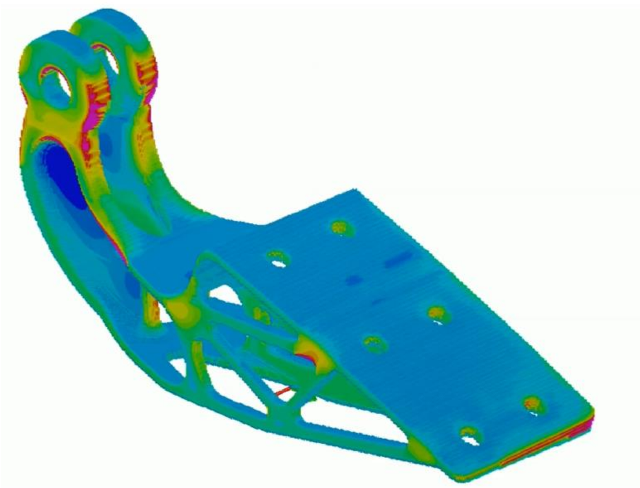


**Figure 3: Example Distortion and Residual Stress Model - Courtesy Bomabrdier Aerostructures & Engineering Services (AMAZE Project)**

## 4.5. Melting

The Melting module resolves the heat source powder interaction to resolve powder melting, evaporation and solidification. The solidified material can be analyzed to determine the expect porosity and surface finish.

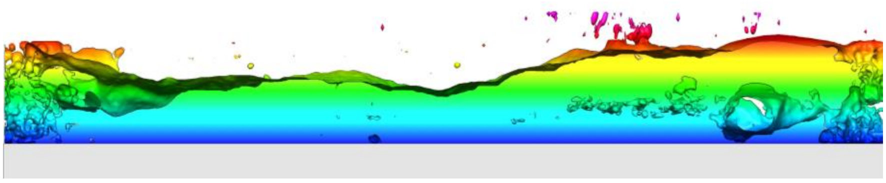


**Figure 4: Example of processing material showing splatter, porosity cloud and crack.**

The utilization of melting models is expected to be required during the printer / powder qualification stage. Once the qualification is concluded, the process window and corresponding porosity and surface finish data will be available in the data base for referencing during future analysis of new work pieces and homogenization algorithms assessing part performance.

# 5. Additional Features

ESI-AM is foreseen to have several automated post processing tools that provide quantitative results. These tools are supported with interactive tools that allow the user to analyze the data separately.

The current prototype does not have its own graphical environment. Other tools from the ESI portfolio are used accordingly.

## 5.1. Preprocessing

Two automated grid generators are used to create computational grids for the Distortion and Residual Stress (CFD-VisCART) and Melting modules (CFD-GEOM). The grid generation is automatic and should not require the user to interact directly with the grid generator. If this should be needed, it is recommended to contact ESI-AM support team.

## 5.2. Post Processing

ESI Visual environment is used to analyze Distortion and Residual Stress results. The user is able to visualized the build process and the evolution of distortion and stresses. Other variable can be calculated including plastic strain, tresca stresses and strains.

CFD-VIEW is used to visualize Spreading and Melting results. Automated video creation tools are available as well as quantitative analysis tools based on CFD-VIEW>