2nd International Workshop on Software Solutions for Integrated Computational Materials Engineering

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Sandbox Scenario 4

Production or repair of Ni-based turbine parts by additive manufacturing (e.g. by selective laser melting – SLM)

Introduction

Additive manufacturing (AM) as an alternative fabrication method has recently managed to move forward from merely prototyping to serial production of first aero engine parts. Additive manufacturing is a highly complex process with a plurality of process parameters and different processing steps.

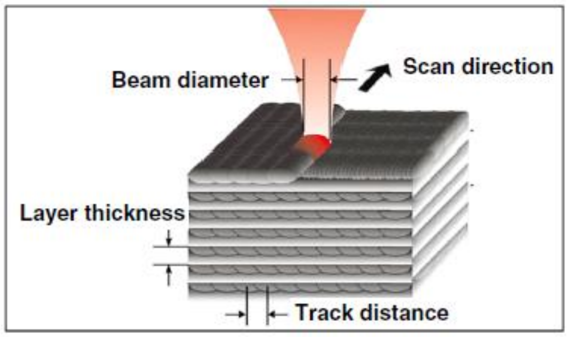

Figure 1: Selective Laser Meting (SLM, Source MTU).

Selective Laser Melting (SLM, Figure 1) offers production of complicated part geometries leading to locally different mechanical properties. A specific feature of this process are high heating and cooling rate because of the local laser melting procedure. In addition, the part by itself shows high internal stresses and distortions. This makes the certification of an aircraft part produced by additive manufacturing challenging. In order to guarantee aviation specific requirements, it is fundamental to understand allowable process parameter variations without losing part integrity and stable mechanical properties.

Process route for the material:

Selective Laser Melting (SLM) is an additive manufacturing process being established for the production of highly individualized products from metallic materials. The process needs powder and creates within one production step a final product with nearly unlimited geometrical design freedom, Figure 2.

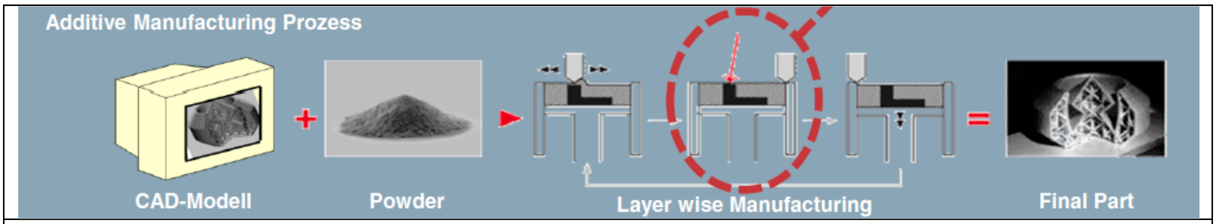

Figure 2: Process chain “Selective Laser Melting” (Source MTU).

Classification of the topic:

1. *Material*: Nickel-base (or alternatively and titanium-base) alloys
2. *Scale* of the material phenomena to be described: Nanoscale (<100 nm), Microscale (100 nm – 1 mm) and Macroscale (>1 mm)
3. *Scope of interest*: metallic components produced by additive manufacturing. Hence, the application involves the fluid state, solidification, solid state component properties and eventually aero-engine parts.
4. *Industrial sector*: Aero engines
5. *Weakness* of actual approach (trial and error, only simplified lab experiment, no full-scale model, etc.): Experimental development and reaching MRL 10 for new parts is rather slow due to the complexity of the process, the large number of variables and the large number of outcomes that need to be assured.

Requirements and expected results to understand the material behavior:

There is a need to understand and to be able to control the interdependencies between Selective Laser Melting (SLM) processing, initial microstructure formation, evolution during heat treatment and resulting local mechanical strength controlling the final component behavior. It is fundamental to understand allowable process parameter variations without losing part integrity and stable mechanical properties.

How materials modelling played a key role in problem solving:

Detailed process understanding helps decision making in process development and testing. Due to the large parameter sets applicable in these AM manufacturing methods and their impact on achievable material properties and quality, support of the manufacturing process development by the use of simulation is highly attractive. With modelling, the various interactions and sensitivities can be investigated independently from each other. This is very important for aerospace applications with their high quality demands and controlled scatter in the resulting material properties.

Description of the simulation strategy needed:

A simulation chain shall be discussed describing all steps of the manufacturing process on “all” relevant length scales. This “through process simulation” captures details of the microstructure, including grains, dendrites and crystal orientation, which in turn enable local materials properties to be determined. These eventually feed into macroscale sub-system models.

Different models will describe different aspects of the process and microstructure evolution as detailed below, Figure 3.

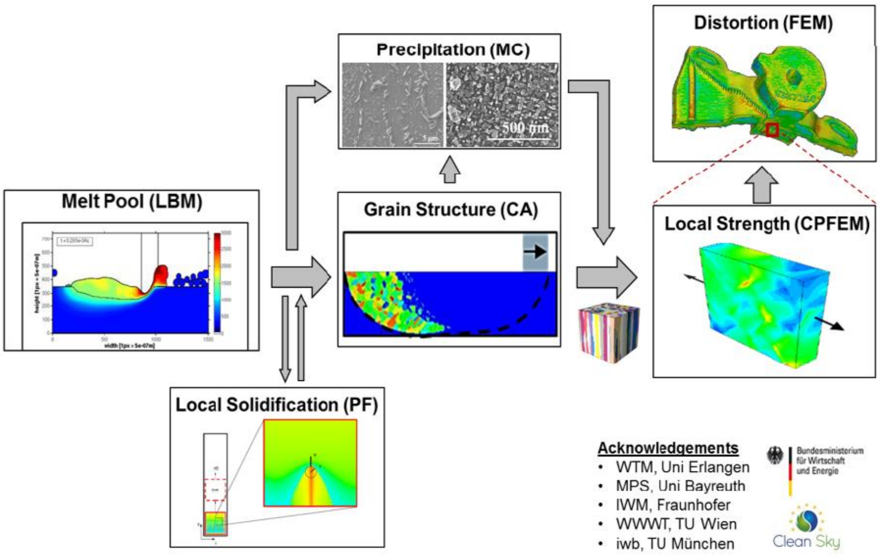

Figure 3: ICME approach for the SLM process includes melt pool generation by powder melting, solidification, phase transformation, precipitation evolution, local mechanical properties and eventually distortion. The full process has to be simulated utilizing according tools.

1. *Melt Pool:*

The local interaction between the laser beam and the powder bed during Selective Laser Melting (SLM) processing has to be modelled including the absorption of the beam by the powder bed and the transfer of energy from laser beam to solid or liquid matter. The model should be able to describe the generation of the powder layer, melting and solidification, melt pool dynamic, capillary forces (Plateau-Rayleigh-effect), gravity, wetting, heat conduction and convection in laser beam melting.

2. *Local Solidification*

A continuum thermodynamics model might describe the initial stage of the solidification process and a microstructure model describes local structure evolution during solidification, considering e.g. the dendritic structure and the crystal orientation formation.

3. *Precipitation*

The time dependent temperature profile resulting from the SLM process can be used as input to a model describing nucleation, precipitation, growth and coarsening.

4. *Mechanical properties*

A continuum model with a constitutive equation for yield and tensile strength solved by the Finite Element method can be applied to the microstructure utilizing the representative volume elements method to capture microscopic features. Model calibration includes the magnitude of solid solution strengthening, dislocation and precipitation strengthening.

5. *Component behavior*

The results are post-processed into material relations that enter as input into continuum mechanical models that calculate macroscale mechanical property of the aero-engine part; where now one finite element represents the previous in detail investigated 1 mm^3.

Open questions to be discussed during the workshop:

1. Can we predict completely through modeling the
    a. Interaction of energy beam with powder (time scales, 3D effects)
    b. Microstructure and/or defect development during solidification and evolution during heat treatment
    c. Chemical composition/ homogeneity
    d. Gradients in properties
    e. Effect on material properties needed for and applied in the subsequent process steps
2. Process route for the product: Can we predict the geometrical accuracy including the residual stress/strain distribution because of the SLM process? At the end of the cycle, the material has typical properties such as hardness.
3. Functional behavior of product: Can we predict performance of product based on calculated properties required for lifetime evaluation?
    a. Local property variations due to gradients in processing
    b. Young's modulus, Poisson ration,
    c. Conductivity, heat capacity, density, thermal expansion coefficient
    d. Static and dynamic mechanical properties (global and local)
    e. Surface roughness