AlphaSTAR

White Paper

Prediction of Mechanical Properties of Powder Metal AM AS-BUILT PART

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Summary: AlphaSTAR has developed the 2015 R&D100 Award winning GENOA 3D print software in collaboration with ORNL and Dassult Systemes. The computaitional tool provides a road map towards product certification and qualification by reducing the printed part scarp rate, time to market, and trial and error printing. GENOA3D Print predicts mechanical properties (static/fatigue) using de-homogenized multi-scale modeling, to determine damage and fracture evolution for metal powder. The software incorporates: (**1**) tool path, for vertical and horizontal printing, (**2**) moving grid to address heat affected zone, (**3**) adaptive meshing to get better thermal distribution, and (**4**) global-local modeling to assess local micro-size damages and residual stress. It has been benchmarked and test validated for multiple materials (i.e., Titanium, Steel, Thermoplastic, and thermoset) and processes (i.e. BAAM, Arc-weld, Powder-bed fusion) [**1**].

Problem: 3D-printed material and parts using DMLS (direct Metal Laser Sintering) may introduce defects in the form of voids, crack, warping residual stress and distortion. Which may cause inconsistency in mechanical properties .

Solution Process Simulation 3D Print: provides a fully coupled thermo-mechanical solution, considering effect of defects, of Additive Manufacturing (AM) process The tool set includes material characterization by multi-scale modeling, manufacturing process parameters (laser power, scan speed, scan pattern), mesh generation and smoothing. GENOA 3D Print Code predict , thermal field, micro-structural defects, residual stress, deflection, and damage and fracture evolution.

Computational Tool Enhancement - ***A computational platform has been developed to improve simulation accuracy and CPU time by using dynamic moving grid, and global/local modeling technique based on the heat effected zone (HAZ) movements.***

The code has been developed to generate FEM model based on heat affected zone movement during the AM process. **Figure 1** shows dynamic moving grid at different time step for a sample case (Single layer of Strati car) revealing temperature distribution and hot zones as the laser moves. It is shown in **Figure 1b** that the thermal gradient is high in bumper area which may cause defects and delaminations [**1**].

Figure 2 shows the growth in the size of HAZ during the manufacturing of a single layer of a prism specimen. This phenomena is a function of the existing heat from previous printed tracks and newly applied heat to the current point of laser location.

Global/Local Model technique allows details assessment of Intergranular/Transgranular void nucleation/growth to predict surface roughness, voids, and oxidation using diffusional creep and grain boundary sliding

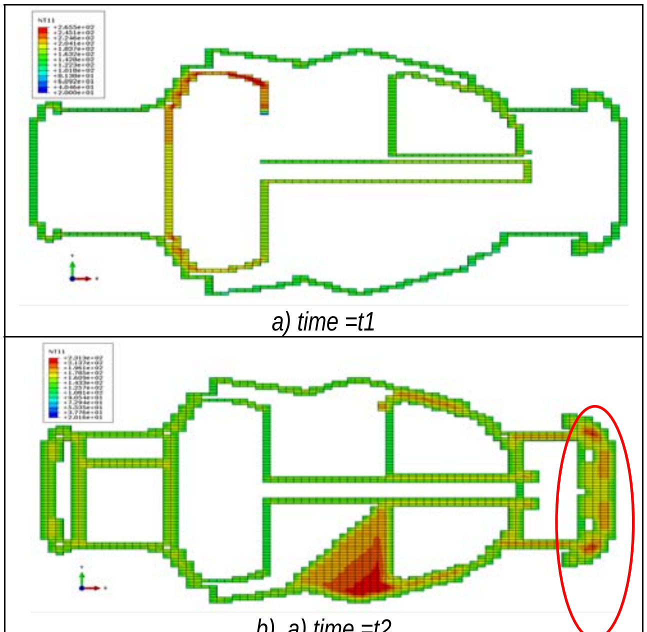


Figure 1. Dynamic Moving Grid Based on Heat affected

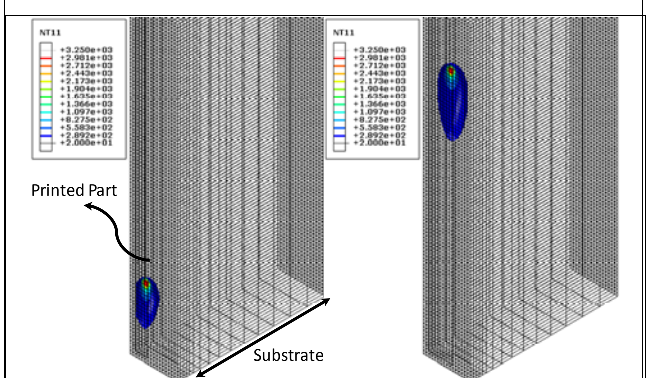


Figure 2. Moving Dynamic Grid Model of Heat Affected Zone Zone at different time step

The approach aims to remedy computational inefficiency and maintain desired accuracy

The key benefit of this approach is the global model can be much coarser while passing detailed information between global/local models such as damage, strain, strain, displacement, etc, as shown in **Figure 3**..

Test Validated AM powder GENOA Simulation Process for 3D-printed Titanium powder metal including: **a**) void and surface roughness, **b**) static stress-strain curve, **c**) fatigue crack growth curve. **Figure 4** shows GENOA predicted metal powder static mechanical properties and qualitative comparison with test data [1]. **Figure 4a** shows **a**) local grain model: void (defect) initiation and growth, surface roughness prediction (40-80 mm) compared with airbus measurements of (50 mm) using diffusional creep algorithm. **Figure 4b** shows GENOA software local modeling of grain and grain boundaries residual stress, surface crack damage evolution, and internal crack porosity. **Figure 5** shows stress strain curve prediction stress-strain curve prediction at room temperature (RT) versus test. For aligned 5% voids with aspect ratio of 5, using nano-based inclusion/defects algorithm. **Figure 6** shows prediction of Ti 6Al 4V – DMLS at RT and comparison with fatigue crack growth, fatigue life (S-N) based on fracture mechanics and fatigue crack growth formulation, and virtual crack closure technique.

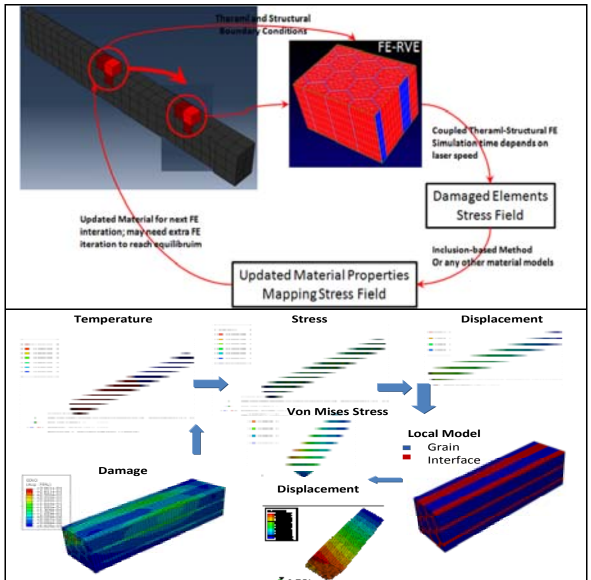
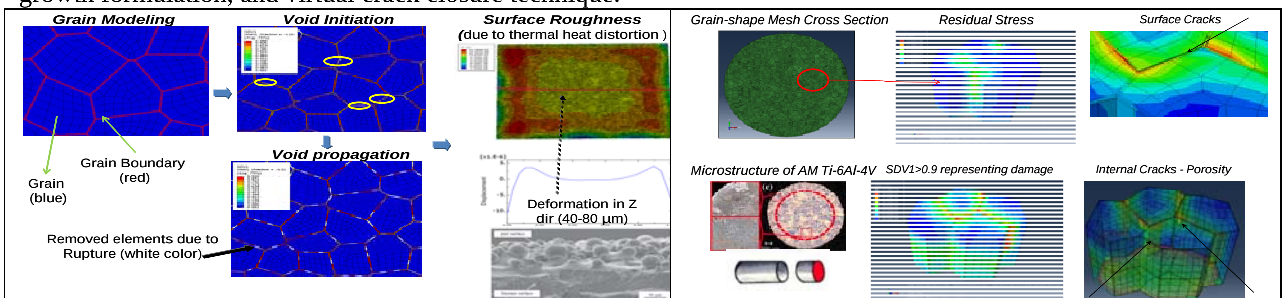


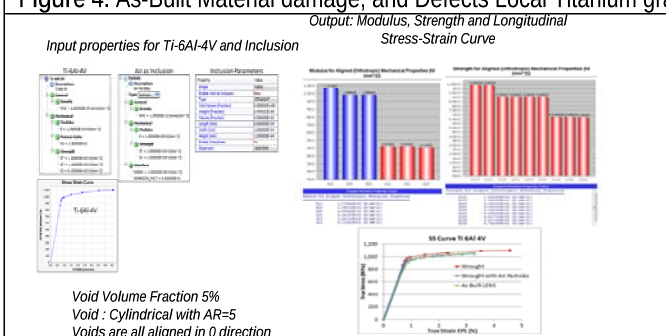
Figure 3. Global/local Multiscale modeling strategy



a) Prediction/Test Void initiation, growth, Surface Roughness

b) Prediction of residual stress, and internal crack porosity

Figure 4. As-Built Material damage, and Defects Local Titanium grain, grain Boundaries Model



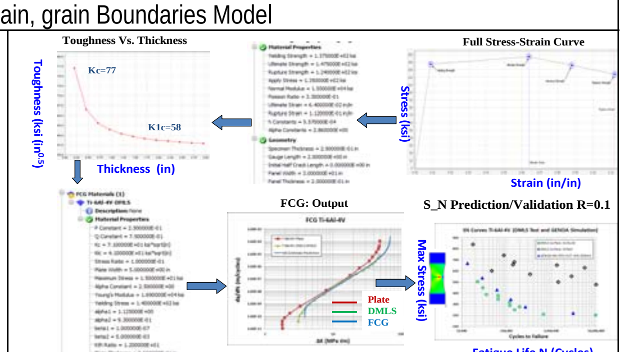


Figure 5. Stress-strain curve prediction Vs. Test, using Nano Based Inclusion/Defects Algorithm

Figure 6. prediction of Ti 6Al 4V – DMLS at Room Temp and comparison with fatigue crack growth, fatigue life (S--N)

Reference

1. M. R. Talagani, S. DorMohammadi, R. Dutton, C. Godines, H. Baid, F. Abdi, V. Kunc , B. Compton, S. Simunovic, C. Duty, L. Love, B. Post, C, Blue, "Numerical Simulation of Big Area Additive Manufacturing (3D Printing) of a Full Size Car". SAMPE Journal, Volume 51, No. 4, July/August 2015.
2. Daniel Greitemeier, Vitus Holzinger, Claudio Dalle Donne, Jens Eufinger, Tobias Melz, " Fatigue prediction of additive manufactured Ti-6Al-4V for aerospace: Effect of defects, surface roughness", 28th ICAF Symposium – Helsinki, 3–5 June 2015.