Test Validated

CASE STUDY

Using GENOA 3DP To Drive AM Part Acceptance

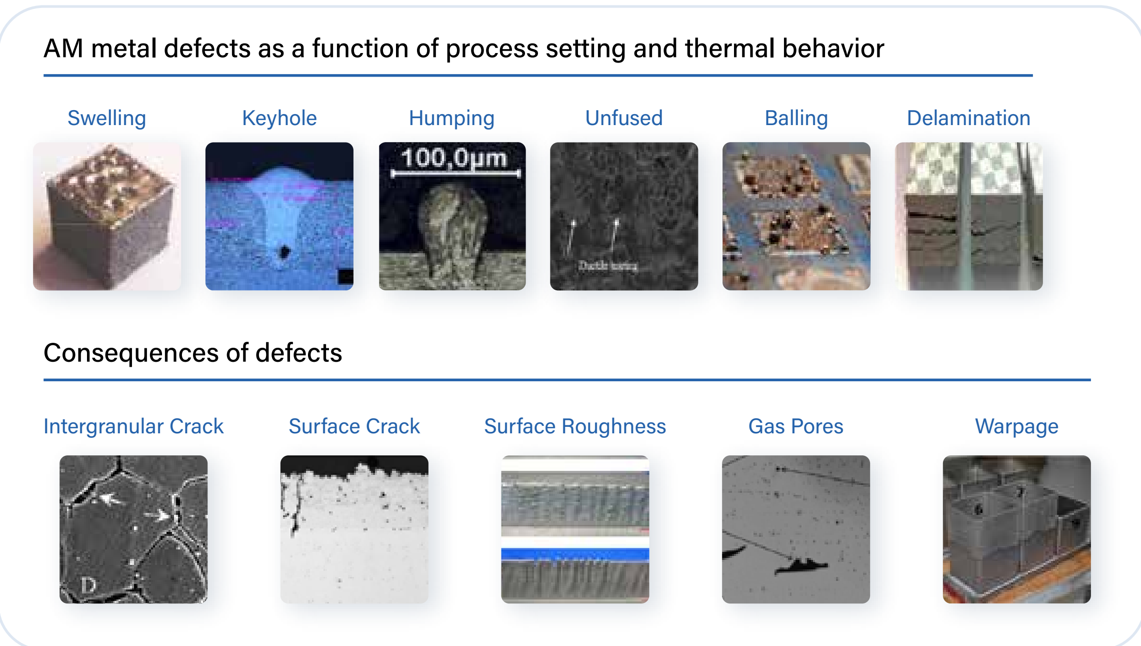
Raytheon Technologies

AlphaSTAR

Challenge

The Missile Defense Agency (MDA) sought to verify that Additive Manufacturing (AM) could be used to affordably build critical and non-critical metal parts. However, AM metal parts generally exhibit surface roughness, warping, voids, and scatter in mechanical properties that make qualification and acceptance difficult (Fig 1). Accordingly, MDA set an objective to develop a method to guide the AM build process and harness its best qualities to produce qualified parts.

FIGURE 1



Solution

AlphaSTAR's GENOA 3DP, an ICME framework, was chosen to address MDA's objectives as it supports multiple modules to simulate the multi-scale thermo-physics of AM. GENOA 3DP provides a reliable and repeatable roadmap in which the additive process can be predicted as a function of material, modality, and build plan. It also identifies print process parameter values to mitigate defects and ensure part quality. Altogether, GENOA 3DP maximizes the efficiency of AM production by:

- Eliminating trial and error builds.
- Reducing time, material, and cost needed to achieve part acceptance.

FIGURE 2

GENOA 3DP WORKFLOW FOR QUALIFICATION

Qualification Catagory	Description
1. Micro defects	Micro voids/density during thermal history, super melting, sintering and solidification
2. Macro defects	Macro porosity. Printing error around hole and boundary
3. Surface roughness	Diffusional creep. Triaxial stress
4. Intergranular cracks	Diffusional creep. Biaxial stress
5. Scatter in material properties	Stress-strain relation (yield stress, ultimate/plastic strain due to voids (micro/macro) and cracks
6. Fracture control plan	Characterization of fracture properties, fatigue crack growth, stress intensity curve
7. Warpage	Evaluation of support. Residual stress
8. Net shape	Residual stress. Baseplate removal
9. As-built performance	In-service loading
10. Past heat treatment	Grain growth, lower strain, thermal analysis

Approach

To address the objectives of the MDA challenge, AlphaSTAR partnered with Raytheon Technologies (RTX) to investigate affordable AM fabrication with an Inconel 718 non-critical mount ring. Through experience, AlphaSTAR identified ten categories related to qualification **(Fig 2)**. However, time considerations limited the scope of investigation to a subset of five categories that focused on common defects, which was sufficient to meet acceptance. The five categories included:

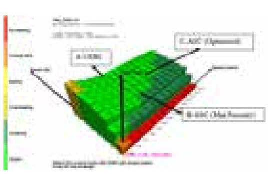
1. Micro voids (density/porosity)
2. Macro-voids
3. Roughness
4. Stress-strain curve addressing scatter and uncertainty
5. Net shape-distortion

The first step was to determine the presence of (1) micro voids. Accordingly, the team used GENOA 3DP's TMg (Thermal Management) module, to generate thermal process and void maps to identify the regions of stability and come up with intelligent print parameter values **(Fig. 3)**. Next, these parameters were implemented at the part level (ex. Mount Ring) and calculated the corresponding thermal history and micro void distribution.

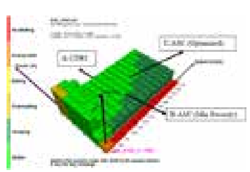
Next, GENOA 3DP's PathCoverage module predicted macro voids as related to printing tool-path errors. These gaps correspond to real locations where material is not present, which lead to a reduction in structural capacity and performance **(Fig 4)**. Model validation was secured with predicted values for cylinders and the full mount ring.

FIGURE 3

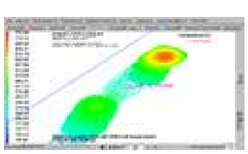
Thermal History & Thermal and Material State



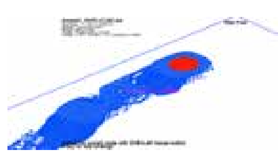
Process Thermal Map



Void Map



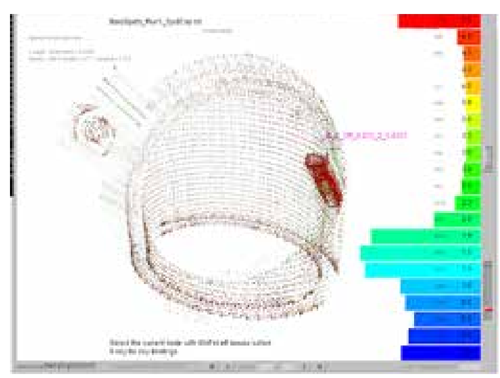
Transient Temperature Distribution



Dynamic Melt-Pool Evolution

FIGURE 4

Macro Voids on Mount Ring

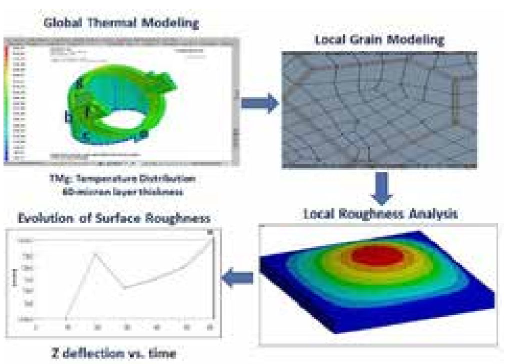


Approach (Cont.)

Continuing, GENOA 3DP's TMg performed element by element/layer by layer thermal analysis, that provided critical information on temperature, temperature-history, voids, void distribution, density, thermal conductivity and considered exact layer thickness in its evaluation. This information was then used to calculate surface (3) roughness. Specifically, GENOA 3DP TMg results provided temperatures and material states as a function of interaction with the laser beam. From here, properties were degraded based on damages and in turn were used to predict defects such as voids, oxidation, and ultimately surface roughness **(Fig. 5)**.

FIGURE 5

Roughness Prediction Workflow



Further, GENOA 3DP's TMg results were used as input to AlphaSTAR's Material Characterization and Qualification (MCQ) software for generating material and thermal cards for the build.

Here, the stress strain curve (4) of heat-treated material system was determined from non-heat-treated material data [1]. It was assumed that due to the heat-treatment process eutectic precipitates (α Al-Silicon) were generated which enhanced material properties.

Stress and strain-based failure criteria were also incorporated to obtain the RTX validated heat-treated stress-strain curve. The overall AM process was simulated using GENOA 3DP sequentially coupled with a thermo-structural FEA analysis. Netshape (5) was one outcome of this analysis. GENOA 3DP was used to set up the model and generated an input file for the FEA solver. Predicted Netshape output showed good agreement with RTX fabricated test-measured specimens, which utilized print parameter values identified by GENOA 3DP.

Result

With the assistance of the GENOA 3DP ICME framework, AlphaSTAR and RTX were able to implement virtual process simulation to assist in part acceptance from RTX in support of the MDA.

In summary, the reduced effort corresponded to savings of cost, time, material, and hardware wear and tear. GENOA 3DP's ICME framework provided an increase in build speed and overall productivity. The final mount ring was smooth, warp free and had low residual stresses. Significantly, part acceptance was achieved with identification of micro-voids, macro-voids, roughness, heat affected stress-strain curve, and netshape.

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