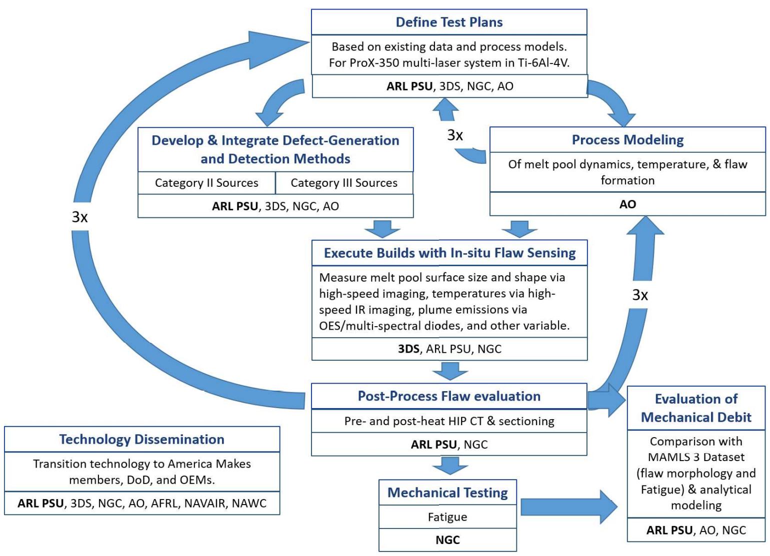
SUCCESS STORY **3026.001**

Project developed and verified controlled formation of process defects during laser powder bed fusion of additive manufacturing Ti-6Al-4V

Data results improved design practices, standards, and certification protocols for AM titanium alloy applications



Project flowchart indicating tasks for project completion and assigned team members.

PROBLEM

It is well established that flaws, such as lack-of-fusion or spherical porosity, occur during Powder Bed Fusion Additive Manufacturing (PBFAM). Depending on their morphology and location, flaws can negatively affect build and part quality. Equally problematic is the lack of guidelines establishing limits on the size, morphology, location of flaws, and verified strategies to estimate the mechanical property debits incurred due to the presence of flaws. The failure to establish accepted models or relationships between flaw characteristics and mechanical properties, to define nondestructive evaluation (NDE) guidelines, to quantify the reliability of sensing methods, and to implement rapid certification/qualification strategies for PBFAM is partly due to the current, limited ability to reproduce flaws, representative of natural ones, in a controlled fashion.

OBJECTIVE

The objectives of this project were to develop methods for repeatable generation of morphologies representative of natural defects during laser PBFAM of Ti-6Al-4V, to demonstrate the similarity of these surrogate defects to naturally occurring ones, and to compare the material debits incurred by surrogate and natural defects. In particular, the work sought to develop methods, based on build plan and process perturbations, for the formation of surrogate defects with known morphologies at a specific location, representative of naturally-occurring flaws; model and predict interactions leading to flaw formation; refine methods to characterize, both in-situ and via NDE, natural and surrogate defects and demonstrate the similarity between both; and establish, quantify, and model relationships between defect characteristics (e.g. morphology, location) and failure under fatigue loading.

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to:

PROCESS

ASTM PROCESS CATEGORY:
Powder Bed Fusion

EQUIPMENT:
3D Systems
ProX-320/A

MATERIAL:
Titanium Alloy
Ti-6Al-4V

TECHNICAL APPROACH

The project team included The Pennsylvania State University Applied Research Laboratory (Penn State), 3D Systems, Applied Optimization, and Northrop Grumman. A test plan was developed to characterize controlled flaws in the PBFAM process. Process modeling of the experimental plan was performed by Applied Optimization. Penn State led the development of in-process anomaly generation methods and in-situ monitoring of flaw generation during sample builds. Test samples were printed using a 3D Systems ProX-320 machine with the developed in-situ monitoring capabilities added. The resultant test samples were then characterized, tested, and analyzed to establish an extensive dataset containing in-process sensor signatures, computed tomography (CT), and metallographic data for identified defect types and morphologies. Resultant hardware, software, and data were transitioned to America Makes and the Department of Defense (DoD) at the conclusion of the effort.

ACCOMPLISHMENTS

Among the methods assessed, sporadic fluctuations of processing power most reliably generate lack-of-fusion and keyhole-induced porosity, representative of that observed in real parts. Analytical models are effective in predicting resulting flaw size and location using the input magnitude, number of layers, and area over which laser power fluctuations are set; though, data-driven models perform better. A key finding of this work was, even with a lack of fusion on the order of 0.8 mm in diameter, located on the order of 1 mm from a machined surface, post-process hot isostatic pressing resulted in high-cycle fatigue performance as good as wrought material. The results of this work are useful for the qualification of AM designs, processes, and components. The developed methods should be used in the generation of specific flaw morphologies (e.g. size, orientation, etc.) at intended locations. If adopted and further developed, the methods reported will enable researchers to systematically evaluate material performance as a function of defect characteristics. Moreover, these methods will enable reliable, model-based guidance on appropriate design limits for defect morphology and locations within components of interest to the aerospace and DoD communities.

PROJECT END DATE

March 2022

DELIVERABLES

- Validated methods, along with hardware and software tools for repeatable generation of surrogate defects
- Modeling software for prediction of defect formation and resulting mechanical performance
- Extensive dataset containing in-process sensor signatures, CT, and metallographic data for identified defect types and morphologies
- Fatigue tested data on at least between 25-100 specimens with intentionally-introduced surrogate defects

FUNDING

$1,373,406 total project budget
($968,568 public funding, $404,838 private funding)

PROJECT PARTICIPANTS

Project Principal:
Pennsylvania State University Applied Research Laboratory

Other Project Participants:
3D Systems
Applied Optimization
Northrop Grumman

Public Participants:
U.S. Department of Defense