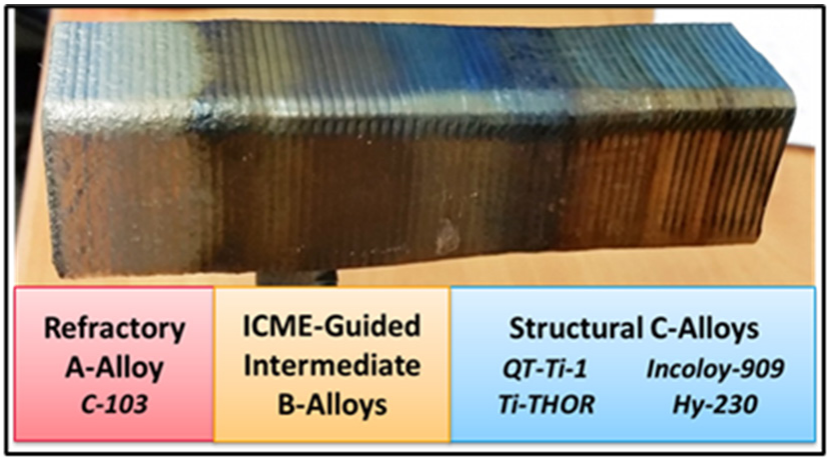
SUCCESS STORY 5001.001.001.007

Project validated higher joint performance for a relevant material set

Graded specimen testing showed the L-DED print process could produce high-quality functionally graded specimens



Graded Alloy Transition Development (GRATD) employs Integrated Computational Materials Engineering (ICME).

PROBLEM

Additive manufacturing (AM) is a valuable enabler for rapidly manufacturing complex assemblies. The Office of the Under Secretary of Research and Engineering's (OUSD R&E) Technology & Manufacturing Industrial Base in collaboration with the Assistant Director, Hypersonics has identified the development of AM for high-temperature metals as key to timely fielding of high-mach capabilities, addressing shortfalls of traditional manufacturing processes which are often costly, low-yield, and labor intensive. Additionally, aero-thermal environments experienced by hypersonic vehicles require joining dissimilar materials to reduce weight and increase thermal/structural performance. Developments in AM techniques for processing high-temperature and dissimilar material sets for high-mach applications are needed to exploit the advantages of AM.

OBJECTIVE

This program aimed to develop graded alloy transitions for high-mach systems by demonstrating and validating the ability of AM techniques to achieve higher joint performance for a relevant material set compared to baseline processing/bonding method(s). This project sought to combine Boeing's high-mach design knowledge and AM experience, QuesTek's state-of-the-art integrated computational materials engineering (ICME) tools, and RPM Innovations proven powder feed direct energy deposition (DED) procedures and build parameters to develop additive-enabled leading and control fin edge transition joints.

AMERICA MAKES TECHNOLOGY DEVELOPMENT ROADMAP

This project aligns to: MATERIAL

ASTM PROCESS CATEGORY
Directed Energy Deposition

EQUIPMENT
N/A

MATERIAL
Niobium alloy tip (C-103), Nickel (Incoloy-909 and Hy-230),Titanium (Ti-THOR and QuesTek Ti-1)

TECHNICAL APPROACH

The GRaded Alloy Transition Development (GRATD) project involved four primary tasks:

1. Identifying and down-selecting graded materials and using ICME tools to perform equilibrium and non-equilibrium (Scheil) thermodynamic calculations at various compositions along the gradient to assess potential formation of undesirable phases (i.e. brittle intermetallic phases) during solidification, thermal exposure, or heat treatment.
2. Developing the transition process(s) and determining the base alloy properties.
3. Characterizing the graded transition interface and properties.
4. Delivering a final report including all project results, conclusions, and recommendations.

ACCOMPLISHMENTS

This project demonstrated the feasibility of using blown metal powder, Laser-Directed Energy Deposition (L-DED) Additive Manufacturing (AM) to deposit functionally-graded structural transitions between C103 niobium (Nb) alloy (niobium-hafnium-titanium [Nb-Hf-Ti]) and three (3) different Ti alloys – Titan-23, QuesTek-Ti, and Ti-6242. Key results, conclusions, and future activities are:

Graded transitions from C103 to Ti-alloys worked well, although concerns with hot cracking susceptibility required avoiding certain mixture ratios.

Wall builds and tensile testing transitioned C103 to Titan-23, QuesTek-Ti-1A and Ti-6242 materials.

- Room temperature tensile tests confirmed failures in the weaker C103 region.
- Vacuum heat treating Ti-alloys did not cause embrittlement or other issues in transition regions.

Graded Transitions from C103 to Ni alloys (Hy-25, Hy-230, and Incoloy-909) were unsuccessful.

- Integrated Computational Material Engineering predicted challenges, i.e., the formation of intermetallics and brittle phases.
- Commercially-pure Vanadium (CP-V) worked well to transition away from C103 with Nb and Hf.
- Transition from CP-V to Ni-based alloys was not successful.
- Deposition of a secondary transition from CP-V to Chromium (Cr) was successful, and was predicted to possibly facilitate Hy-25 transition.
- Cracks occurred when attempting 80w% Chromium (Cr) /20w% Hy-25 deposition on a Cr layer.

PROJECT END DATE

July 2022

DELIVERABLES

- Annual Briefing to America Makes Members
- Final Project Report to include:
  - Desired alloy material systems
  - Calculation results for selected A-C and A-B-C gradient systems
  - Compositions of selected B inter-layers
  - Recommendations for gradient strategies, i.e., composition paths
  - Material gradient builds and test results of material gradient builds

FUNDING

$844,193 total project budget
($465,731 public funding/$378,462 private funding)

PROJECT PARTICIPANTS

Project Principal:
The Boeing Company

Other Project Participants:
QuesTek Innovations, LLC
RPM Innovations, Inc.

Public Participants:
U.S. Department of Defense