Request for White Paper

Hypersonic Thermal Research and Material Acceleration - Metallics

Table of Contents

Where Manufacturing Technology and Talent Matter

October 14, 2021

Program Abstract

The program funded under this effort has the goal of continuing the development of ICME (Integrated Computational Materials Engineering) models for materials suitable for hypersonic vehicles. LIFT has invested in and is developing a significant ICME model database for hypersonic materials via team projects. LIFT will print metallics used in hypersonic vehicles via a laser powder bed fusion 3D printer and then test them through various heat and stress/strain cycles to determine "real world" material properties. Materials to include alloys such as Inconel X-750, Ti-6242, and intermetallic Ti-Al alloys. Material properties will then be compared and contrasted to the ICME models. Deviations will be used to fine-tune models to provide accurate results in future application usage. These models will be loaded into a materials database accessible by suppliers and manufacturers to the Army, Air Force, and Navy. Further development and optimization of the ICME capability will enable faster design and higher-quality manufacturing. Focusing this capability on DoD systems and components will bring new tools to the warfighter at greater speed and lower cost.

This program will define opportunities for mechanical property optimization of metallic alloys used in hypersonic vehicles. ICME models that accurately predict the performance of new metallic alloys and ceramic/CMC materials will be created. Manufacturing supply chain(s) for new metallic alloy powders will be established. The mechanical properties predicted through ICME models will be correlated through real-world testing. Disparate metallic alloys will be joined through solid-state joining techniques. The materials database will be augmented with performance results of new alloys and Ceramic/CMC's.

Period of Performance: May 2021 through December 2023

Requested Services – Statement of Work

Phase 1: to be completed by February 2023

A) Evaluate 1 Commercial off the shelf (COTS) Metal:

Staff or graduate student team to collaboratively work with LIFT to:

- Laser-powder bed fusion additively manufacture (L-PBF AM) 1 commercial off the shelf (COTS) metallic material of interest for a hypersonic application at the LIFT Corktown facility using a mutually agreed upon designed experiment.
- Specimens to be heat treated, machined, imaged via CT scanning, and HIP'd as necessary to develop quality microstructural, tensile, and rotary bend fatigue specimens.
- Test the COTS AM tensile bars at the LIFT Corktown facility.
- Perform metallographic prep and microstructural analysis sufficient to fully characterize the AM material. Compare to in-situ thermal monitoring results and simulation predictions to be provided by LIFT.
- Compare mechanical and microstructural behavior to LIFT ICME predictions and to analogous cast materials.
- Print same COTS material into hypersonic test specimens. Heat treatment, machining, CT scanning, and HIP-ing to be performed at LIFT facility as needed to produce quality parts.
- Compare hypersonic in-test response and post-test mechanical and microstructural behavior to LIFT ICME predictions.
- Collaboratively work with LIFT to identify alloying opportunities to improve alloy response to a hypersonic environment.

B) Fatigue Testing

- Perform rotary fatigue testing to run-out of AM specimens manufactured from 2 COTS metals. Test parameters to be mutually agreed upon depending upon materials to be tested. Up to approximately 30 specimens per alloy. LIFT to compare to literature values.

C) Hypersonic

- Ability to model material & part in hypersonic fluid dynamic environment (metal, ceramic, metal-metal joint, metal-ceramic joint)
- Ability to validate hypersonic model with physical testing and perform iterative improvements to hypersonic model to match model results to physical test results. Test specimens include additively manufactured metallic components and components joined via linear friction welding.
- Ability to support integration of hypersonic models in LIFT computational toolchain

- Physical hypersonic testing to include high enthalpy reaction facility capable of:
    - Test section flow Mach #s: Full range from 4 to 7
    - Testing run time: Minimum 1 minute of test section reacting run time and 35 minutes of non-reacting flow
    - Specimen size: Minimum 45mm x 45mm
    - Stagnation pressures: Up to 2,000 psi
    - Stagnation Temperatures: Exceed minimum critical temperature of 1,200K with preference to test up to 2,000K using Air/O2 or H2/O2 burner with options to evaluate at higher temperatures up to 4,000K for ablation/combustion studies
    - With corresponding low cost of operation compared to National facilities, ie., AEDC, NASA, AFRL, etc.
    - In-situ monitoring of the hypersonic test including high speed camera(s), temperature and pressure sensors, and surface analysis of material structure-property changes during reacting run time and non-reacting flow. Ability to pinpoint at what time during test melting/surface modification begins.
    - Post-test structure-property evaluations to include microstructural & mechanical evaluation"
- 1 month turnaround time for hypersonic testing prep/set-up, test run time, data analysis, and recommendations for model/material/part modifications
- Work collaboratively with LIFT to develop road map for alloy/process development for this COTS material in a hypersonic environment

Phase 2: to be completed by October 2023

Novel Alloy Development & Production

- Perform literature review and CALPHAD (Thermo-Calc) simulation to design a new metallic alloy based on the COTS material evaluated in Phase 1. Work collaboratively with LIFT to reach final agreement on alloy design using results from LIFT's integrated processing-structure-properties-performance toolchain
- In-house (not sub-contracted) gas atomization system with induction melting furnace (50kW - 1650C capability) capable of manufacturing at least 5kg at a time, 10kg preferred
- Manufacture usable quantities of 2 novel metallic alloys as identified by LIFT and relevant to hypersonic environment to support evaluation of novel metal AM. Total quantity required dependent upon materials selected. Estimated in the 20-30kg range total to be manufactured in 5-10kg batch sizes.
- Laser diffraction particle size analysis of both manufactured alloys. Iterate on melting/gas atomization as necessary to obtain agreed upon size distribution.

- Powder shape analysis of both manufactured alloys. Iterate on melting/gas atomization as necessary to obtain agreed upon shape distribution.
- Chemistry analysis of both manufactured alloys. Iterate on melting/gas atomization as necessary to obtain agreed upon chemistry.
- Laser-powder bed fusion additive capabilities to perform proof of concept testing on manufactured alloys to confirm viability in processing environment and to iterate on alloy development or production as necessary

Evaluate 1 Novel Metal:

Full time person (staff or graduate student) to work collaboratively with LIFT to:

- Laser-powder bed fusion additively manufacture (L-PBF AM) 1 novel metallic alloy of interest for a hypersonic application at the LIFT Corktown facility using a mutually agreed upon designed experiment.
- Specimens to be heat treated, machined, imaged via CT scanning, and HIP'd as necessary to develop quality microstructural, tensile, and rotary bend fatigue specimens.
- Test the tensile bars at the LIFT Corktown facility.
- Perform metallographic prep and microstructural analysis sufficient to fully characterize the AM material. Compare to in-situ thermal monitoring results and simulation predictions to be provided by LIFT.
- Compare mechanical and microstructural behavior to LIFT ICME predictions and results from Project Phase 1. Identify if hypersonic testing is of value or if alloy design iteration required.
- Print novel alloy into hypersonic test specimens. Heat treatment, machining, CT scanning, and HIP-ing to be performed at LIFT facility as needed to produce quality parts.
- Hypersonic modeling & testing to be performed as outlined in Project Phase 1.
- Compare hypersonic in-test response and post-test mechanical and microstructural behavior to LIFT ICME predictions.
- Perform rotary fatigue testing of the novel alloy AM specimens in relation to the print strategy. Compare to literature values.

Fatigue Testing

- Perform rotary fatigue testing to run-out of AM specimens manufactured from 2 novel metal alloys. Test parameters to be mutually agreed upon depending upon materials to be tested. Up to approximately 90 specimens per alloy. LIFT to compare to literature values.

Linear Friction Weld Hypersonic Testing

- Hypersonic testing to be performed as outlined in Project Phase 1 on mutually agreed upon specimens that have been solid stated joined via linear friction welding.

Phase 1 RASIC Chart

R – Responsible, A – Approve, S – Support, I – Inform, C - Consult

Task	LIFT	Sub-Award Project Lead
Evaluate 1 COTS Metal at LIFT Corktown Facility		
L-PBF 1 COTS Metal	R	S*
Post processing (heat treat, machining, CT scanning, HIP)	R	S*
Tensile tests	S	R
Microstructural analysis	S	R
Compare experiments to ICME predictions	R	S
Print hypersonic test specimens	R	S*
Post processing as above	R	S*
Identify alloying opportunities	R	S
Fatigue Testing		
Produce rotary bend fatigue specimens	R	S*
Rotary bend fatigue testing	A	R
Hypersonics		
Model material & part in hypersonic fluid dynamic environment	A	R
Validate hypersonic model with physical testing	A	R
Integration of hypersonic models in LIFT toolchain	R	S
Compare hypersonic in-test & post-test behavior to ICME predictions	R	S
Road map alloy/process development for COTS material in hypersonic environment	R	S

* Sub-Award project lead expected to have physical presence in LIFT Corktown facility to support these activities

Phase 2 RASIC Chart

R – Responsible, A – Approver, S – Supporting, I – Informed, C - Consulted

Task	LIFT	Sub-Award Project Lead
Alloy Development & Production		
Design new metallic alloy based on Phase 1 COTS material	A	R
Manufacture 2 novel metallic alloys (1 from LIFT, 1 from sub-awardee)	A	R
Particle size analysis	A	R
Particle shape analysis	A	R
Chemistry analysis	A	R
L-PBF of manufactured powders to confirm viability	A	R
Evaluate 1 Novel Metal at LIFT Corktown Facility		
L-PBF 1 novel metallic alloy	R	S*
Post processing (heat treat, machining, CT scanning, HIP)	R	S*
Tensile tests	S	R
Microstructural analysis	S	R
Compare experiments to ICME predictions	R	S
Print hypersonic test specimens	R	S*
Post-processing as above	R	S*
Hypersonic modeling as in Phase 1	A	R
Hypersonic testing as in Phase 1	A	R
Compare hypersonic in-test & post-test behavior to ICME predictions	R	S
Fatigue Testing:		
Produce rotary bend fatigue specimens	R	S*
Rotary bend fatigue testing	A	R
Linear Friction Weld Hypersonic Testing		
Produce linear friction welded joints	R	C
Hypersonic testing of linear friction joints	A	R

* Sub-Award project lead expected to have physical presence in LIFT Corktown facility to support these activities

Where Manufacturing Technology and Talent Matter

Expectation of a LIFT Project Partner

- Open to all LIFT members
  - All project consortium members must be a LIFT member in good standing for award
  - Non-members may submit white papers but must join membership as appropriate
- Regular communications/summaries to be provided by the partner, including:
  - Weekly review updates
  - Quarterly reports
  - Final Report
- Demonstration of International Traffic in Arms Regulations (ITAR) Compliance
- Development research is expected to be accomplished internally, without the use of subcontractors

Deliverables

- Financial Plan
- Timing Plan
- Resource plan

Note: Responding to this Request for White Paper for services does not require the provider to be able to support the entire request. Should there be aspects that cannot be supported, simply note those on the white paper.

Submission Due Date: November 5, 2021

Submission Portal: https://lift.technology/project-calls/

Contact Information

George Panourgias
LIFT Program Director
E: gpanourgias@almmii.org