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LLNL-TR-821117

Development of Powder Bed Printing (3DP) For Rapid and Flexible Fabrication of Energetic Material Payloads and Munitions Final Report CRADA No. TC02250.0

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Disclaimer

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Development of Powder Bed Printing (3DP) For Rapid and Flexible Fabrication of Energetic Material Payloads and Munitions

Final Report
CRADA No. TC02250.0
Date Technical Work Ended: July 8, 2017

Date: November 17, 2017 Revision: 0

A. Parties

This project was a relationship between Lawrence Livermore National Security (LLNS) and Makel Engineering, Inc.

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B. Project Scope

This was a collaborative effort between Lawrence Livermore National Security, LLC as manager and operator of Lawrence Livermore National Laboratory (LLNL) and Makel Engineering, Inc., ("MEI"), to develop powder bed printing approaches for fabrication of energetic material payloads and munitions.

The overall objective of this CRADA project was to develop and demonstrate the use of powder bed printing (3DP) for the rapid and flexible fabrication of energetic material payloads and munitions. The specific objectives were:

Objective 1: Define 3DP Process Modifications for Reactive Materials.
Objective 2: Select Suitable Reactive Materials.
Objective 3: Fabricate and Evaluate Parts.

This CRADA project was originally scheduled for seven (7) months; and consisted of one phase, four major tasks, and the following deliverables:

MEI was the prime contractor in the STTR Phase I, and was responsible for progress and final reporting to DTRA, as follows:

- Progress report #1 to DTRA, End of Month 1
- Progress report #2 to DTRA, End of Month 2
- Progress report #3 to DTRA, End of Month 3
- Progress report #4 to DTRA, End of Month 4
- Progress report #5 to DTRA, End of Month 5
- Progress report #6 to DTRA, End of Month 6
- Final report to DTRA, End of Month 7 (End of program)

LLNL, as the subcontractor and research partner was responsible for delivering reporting of its contributions, and sample materials for testing at MEI as follows:

Task 1 Deliverable:
1.1 LLNL to deliver a brief report summarizing methods to be investigated, end of Month 1

Task 2 Deliverables:
2.1 MEI to deliver a report on the assessment of design flexibility.

Task 3 Deliverable:
3.1 LLNL to deliver a brief report summarizing material selection, end of Month 4

Task 4 Deliverables:
4.1 LLNL to deliver samples for testing to MEI, Month 5
4.2 LLNL and MEI will deliver a report summarizing test results, end of Month 6
4.3 LLNL and MEI to deliver Final Report and Abstract due within thirty (30) days of completion or termination of the project, as required under Article X of the CRADA. (LLNL/MEI)

All project deliverables were met. No property was exchanged and no outstanding liens exist.

C. Technical Accomplishments

As summarized in Table 1, all objectives of the Phase I program were met or exceeded. The fabrication processes have been defined and the equipment has been configured to enable processing of energetic materials (Task 1). Parts to assess manufacturability have been designed and fabricated (Task 2). The reactive powder and infiltration materials has been selected (Task 3). Parts were fabricated and characterized to determine key mechanical, thermal and reactive properties (Task 4).

Table 1. Meeting or Exceeding Phase I Objectives

Objective	Status
Objective 1: Define 3DP Process Modifications for Reactive Materials.	The fabrication processes have been defined and the equipment has been configured to enable processing of energetic materials
Objective 2: Select Suitable Reactive Materials	Reactive powders and infiltration materials have been selected.
Objective 3: Fabricate and Evaluate Parts.	Parts were fabricated and characterized to determine key mechanical, thermal and reactive properties

D. Expected Economic Impact

This Phase 1 STTR was a short-term project focused on development and technical refinement of a new method for manufacturing of energetic materials and munitions. The Phase 2 STTR was the anticipated mechanism for tech transfer and further investment. Unfortunately, the Phase 2 was not funded by the funding agency so a significant economic impact was not realized.

D.1 Specific Benefits

Benefits to DOE

The technology to be developed will enhance LLNL core competencies in additive manufacturing and energetic materials.

Benefits to Industry

The industrial benefit to this development project was the increased technical refinement of LLNL intellectual property available for license and the possible transfer of the developed technology from LLNL for industrial use.

E. Participant Contribution

Makel engineering participated in this Phase 1 STTR through project management, technical reporting, testing of experimental articles, and analysis of test results. All deliverables were met. Continued funding from the funding agency for a Phase 2 STTR was not received, so further efforts are not anticipated. No subject inventions were created during this CRADA project.

F. Documents/Reference List

Reports

Development of Powder Bed Printing (3DP) for Rapid and Flexible Fabrication of Energetic Material Payloads and Munitions, Progress Report #1, MEI-DTR01-PR01, LLNL-SR-708339

Development of Powder Bed Printing (3DP) for Rapid and Flexible Fabrication of Energetic Material Payloads and Munitions, Progress Report #2, MEI-DTR01-PR02, LLNL-SR-713497

Development of Powder Bed Printing (3DP) for Rapid and Flexible Fabrication of Energetic Material Payloads and Munitions, Progress Report #3, MEI-DTR01-PR03, LLNL-SR-717697

Development of Powder Bed Printing (3DP) for Rapid and Flexible Fabrication of Energetic Material Payloads and Munitions, Progress Report #4, MEI-DTR01-PR04, LLNL-SR-730123

Development of Powder Bed Printing (3DP) for Rapid and Flexible Fabrication of Energetic Material Payloads and Munitions, Progress Report #5, MEI-DTR01-PR05, LLNL-SR-726823

Development of Powder Bed Printing (3DP) for Rapid and Flexible Fabrication of Energetic Material Payloads and Munitions, Progress Report #6, Final Report Draft, MEI-DTR01-PR06, LLNL-SR-727702

Development of Powder Bed Printing (3DP) for Rapid and Flexible Fabrication of Energetic Material Payloads and Munitions, Final Report, MEI-DTR01-FR, LLNL-SR-730057

Copyright Activity

None

Subject Inventions

None

Background Intellectual Property

LLNL disclosed the following background intellectual property:

United States Patent Applications:

U.S. Patent Application No. 15/019,524[Published No. 20170225389] – *Combing Additively Manufacturing Parts with an Infill Step for Customizable and Novel Energetic Systems*; Inventors: Alexander E. Gash, John Vericella, Kyle Sullivan, Robert V. Reeves; Filing Date: 2/9/16 (IL12904)

MEI did not license the background intellectual property.

G. Acknowledgement

Industrial Participant's signature of the final report indicates the following:

1) The Participant has reviewed the final report and concurs with the statements made therein.
2) The Participant agrees that any modifications or changes from the initial proposal were discussed and agreed to during the term of the project.
3) The Participant certifies that all reports either completed or in process are listed and all subject inventions and the associated intellectual property protection measures generated by his/her respective company and attributable to the project have been disclosed and included in Section E or are included on a list attached to this report.
4) The Participant certifies that if tangible personal property was exchanged during the agreement, all has either been returned to the initial custodian or transferred permanently.
5) The Participant certifies that proprietary information has been returned or destroyed by LLNL.

Dr. Darby Makel, President
Makel Engineering, Inc.

Robert Veeh Reeves, LLNL Principal Investigator
Lawrence Livermore National Security, LLC
Lawrence Livermore National Laboratory

11/21/17

Michael S. Sharer, Manager, Technology Commercialization
Lawrence Livermore National Security, LLC
Lawrence Livermore National Laboratory
Innovation and Partnerships Office

Attachment I – Final Abstract

Development of Powder Bed Printing (3DP) for Rapid and Flexible Fabrication of Energetic Material Payloads and Munitions

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B. Purpose and Description

This was a collaborative effort between Lawrence Livermore National Security, LLC as manager and operator of Lawrence Livermore National Laboratory (LLNL) and Makel Engineering, Inc., ("MEI"), to develop and demonstrate the use of powder bed printing (3DP) for the rapid and flexible fabrication of energetic material payloads and munitions.

The specific Phase I technical objectives are listed below. All technical objectives and tasks were completed.

Objective 1: Define 3DP Process Modifications for Reactive Materials.
Objective 2: Select Suitable Reactive Materials.
Objective 3: Fabricate and Evaluate Parts.

C. Benefit to Industry

The industrial benefit to this development project was the increased technical refinement of LLNL intellectual property available for license and the possible transfer of the developed technology from LLNL for industrial use.

D. Benefit to DOE/LLNL

The technology and processes developed enhanced LLNL core competencies in additive manufacturing and energetic materials.

E. Project Dates

December 8, 2016 through July 8, 2017