REPORT DOCUMENTATION PAGE

Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
13-09-2018	Final Report	15-May-2017 - 14-May-2018

4. TITLE AND SUBTITLE
Final Report: Nano-mechanical testing system for laser deposition-additive manufacturing of superior performance nano-structured metal based materials

5a. CONTRACT NUMBER
W911NF-17-1-0270

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
611103

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSOR/MONITOR'S ACRONYM(S)
ARO

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
69998-MS-RIP.1

12. DISTRIBUTION AVAILIBILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Weilong Cong
UU	UU	UU	UU		19b. TELEPHONE NUMBER 806-834-6178

Standard Form 298 (Rev 8/98)
Prescribed by ANSI Std. Z39.18

RPPR Final Report
as of 13-Sep-2018

Agency Code:

Proposal Number: 69998MSRIP **Agreement Number: W911NF-17-1-0270**

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Report Date: 14-Aug-2018 Date Received: 13-Sep-2018
Final Report for Period Beginning 15-May-2017 and Ending 14-May-2018
Title: Nano-mechanical testing system for laser deposition-additive manufacturing of superior performance nano-structured metal based materials
Begin Performance Period: 15-May-2017 **End Performance Period:** 14-May-2018
Report Term: 0-Other
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Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 1 **STEM Participants:** 4

Major Goals: This proposal desires to acquire a nano-mechanical testing equipment for measurements of compressive and tribological properties on superior performance nanostructured metal based materials fabricated by laser deposition-additive manufacturing (LD-AM) for both research and education purposes. The objectives of this acquisition are: To generate new enablers for superior performance nanostructured metal based material developing and high ends defense device manufacturing, which are desired by AFOSR, ARO, and ONR; To develop processing-property-performance relationships by integrating the requested equipment with existed equipment; To enhance the capabilities for fabrication and remanufacturing of difficult-to-machine and high failure resistance parts by LD-AM; and To support and improve DoD desired university STEM education for future U.S. domestic workforce in the areas of advanced manufacturing and material science.

Many DoD interested superior failure-resistant materials (bulk parts and coatings) have been fabricated by the LD-AM process. These materials include nanostructured super alloys, nanoparticle or nano-precipitate reinforced metal matrix composites, and high indentation and creep resistance thin film materials. The requested equipment will be a key instrumentation for fabricated parts testing and evaluation. The obtained nanoscale mechanical properties can provide better understandings of LD-AM processing mechanism which will benefit the current defense industry desired materials fabrication, special military applicable structure deposition, and new materials development. The requested equipment will promote current LD-AM researches and enable new research areas.

For STEM educations, the requested equipment will bring additional capabilities and more knowledge and practical experiences for material testing to both undergraduate and graduate level manufacturing courses and provide positive impact on education of defense industry desired workforces and engineers for other manufacturing industries. With urgent needs from both faculties and students, it will also play an important role in the following disciplines: industrial engineering, mechanical engineering, chemical engineering, and material science.

Accomplishments: Grant Number: W911NF-17-1-0270 ARO 2017
Title: Nano-mechanical testing equipment for laser deposition-additive manufacturing (LD-AM) of superior performance nanostructured metal based materials

With the funded ARO DURIP grant, a piece of nano-mechanical testing equipment, Nanovea PB1000, was purchased in February 2018 from the Nanovea Inc. (Irvine, CA, USA) with the total cost of $186,598.12. The equipment was delivered in May 2018 and was fully installed on June 16 2018.

The acquired equipment includes two modules with wide testing capabilities ranging from nanoscale to macroscale. PB1000 comes with automated three-dimensional motorized linear stages with a range of 150 mm × 150 mm × 50 mm, a spacious and open platform with adjustable height clearance, a rotation stage for rotative wear testing, and an AFM profiler. With these components, PB1000 is capable of measuring both compressive and tribological properties. In addition, PB1000 can also accommodate the heating oven and the cooling chamber to mimic the extreme temperature conditions in defense industries.

The nano-mechanical testing equipment has attracted attentions from both the academia and the defense industry by demonstrating following key capabilities: (1) load-bearing testing: to evaluate load-bearing stability under a broad range of loading regimes; (2) friction and wear testing: to test friction coefficient and wear resistance under severe conditions; (3) adhesion performance testing: to assess the adhesion properties (e.g. critical loads) of coatings, providing characterization of the abrasion resistance of materials; (4) indentation testing: to accurately and precisely measure hardness and elastic modulus of nanostructured materials; (5) lubrication testing: to test lubricity of self-lubrication materials; (6) atomic force microscope (AFM) imaging: to observe the 3D topographies of the sample surface at a high resolution.

The acquired equipment has been used to conduct nano-mechanical tests (such as hardness tests and wear/friction resistance tests) on laser deposition - additive manufacturing (LD-AM) fabricated TiBw reinforced titanium matrix composites and Inconel 718 alloys. The obtained results are necessary foundations to build processing-nanosturcture-property relationships of fabricated composites and alloys, providing guidance on fabricating high quality and high performance nanostructured materials for defense industries.

In the future, this equipment will be used to conduct nano-scratch testing, nano-indentation testing, and friction testing on nano-sized Al_2O_3 reinforced composite coatings. Obtained results will reflect effects of nano-sized reinforcements on nano-mechanical properties of coatings, thus contributing to developing new ceramic reinforced coatings for metal materials. Due to its capability of providing testing information and identifying types of wear (e.g. fatigue wear, abrasive wear, etc.), the acquired equipment will be used to enable the following tasks: (1) Investigating effects of different rare earth element based compounds on self-lubrication properties; (2) Fabrication of multi layers or even bulk self-lubrication parts by using LD-AM; and (3) Better understanding the fundamental mechanism of the self-lubrication phenomena.

Beyond the proposed research activities, the acquired equipment has also been applied to conducting mechanical tests (such as nano-indentation test and fracture toughness test) on Al_2O_3 and ZrO_2 toughened Al_2O_3. In the future, the acquired equipment will be used for other materials, such as titanium-silver alloys and graphene oxide reinforced IN718, those can be applied to biomedical, high-end engineering, and other DoD desired industries. The obtained results and generated knowledge will provide preliminary results and novel ideas on new proposals writing.

Training Opportunities: Three Ph.D. students received two-day nano-mechanical testing equipment training.

Results Dissemination: Experimental investigations are condcuting using this machine. The results will be disseminated through the publications.

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

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Participant: Weilong Cong

Person Months Worked: 1.00
Funding Support:
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

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Person Months Worked: 1.00
Funding Support:
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
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Technical Reporting

Grant Number: W911NF-17-1-0270 ARO 2017

Title: Nano-mechanical testing equipment for laser deposition-additive manufacturing (LD-AM) of superior performance nanostructured metal based materials

1. Final Performance Report of the Acquired Equipment

With the funded ARO DURIP grant, a piece of nano-mechanical testing equipment, Nanovea PB1000, was purchased in February 2018 from the Nanovea Inc. (Irvine, CA, USA) with the total cost of $186,598.12. The equipment, as shown in Figure 1, was delivered in May 2018 and was fully installed on June 16 2018.

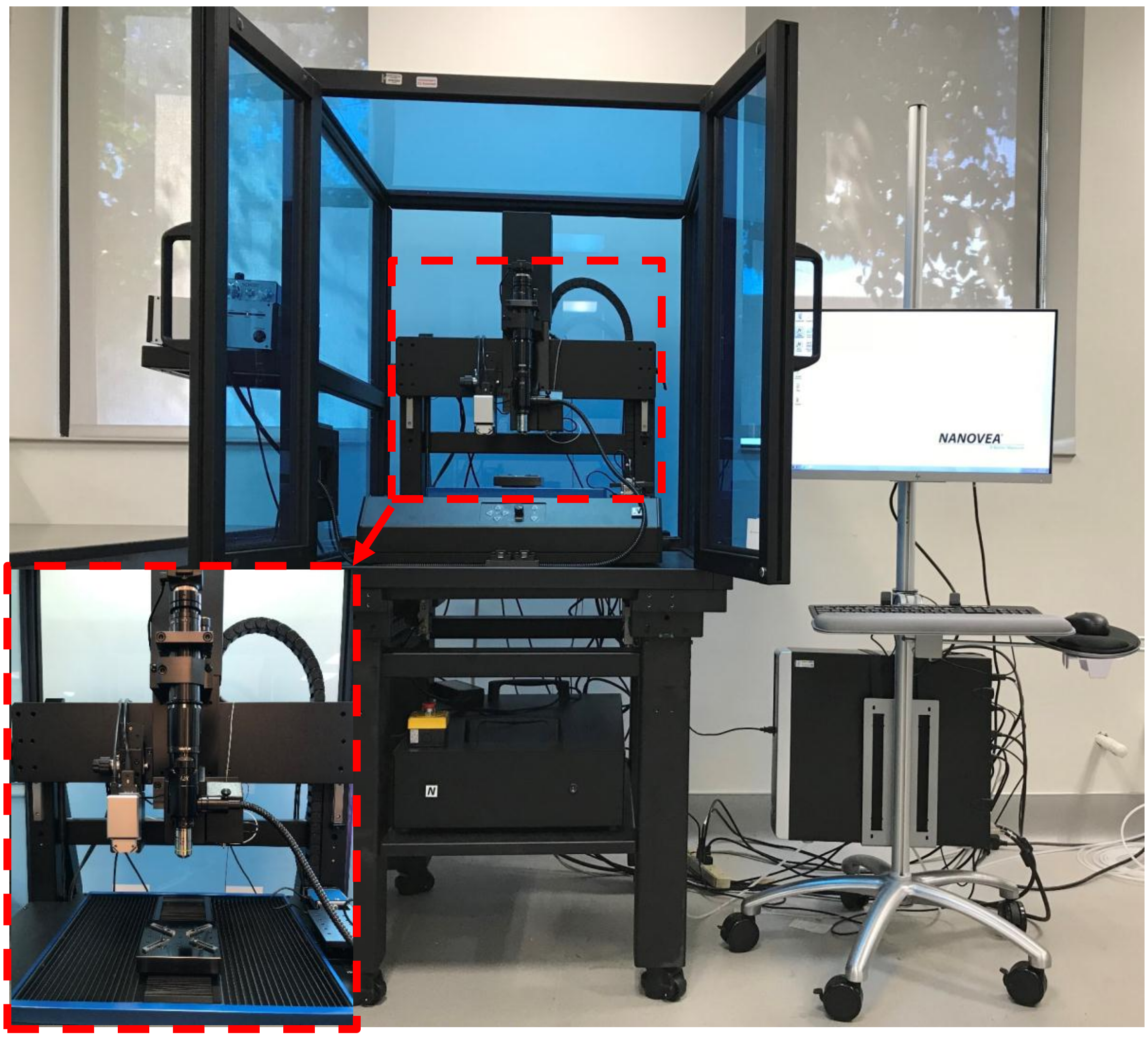


Figure 1. The acquired and fully installed PB1000 testing equipment.

The acquired equipment includes two modules with wide testing capabilities ranging from nanoscale to macroscale. PB1000 comes with automated three-dimensional motorized linear stages, as shown in Figure 2, with a range of 150 mm $\times$ 150 mm $\times$ 50 mm, a spacious and open platform with adjustable height clearance, a rotation stage for rotative wear testing, and an AFM profiler. With these components, PB1000 is capable of measuring both compressive and tribological properties. In addition, PB1000 can also accommodate the heating oven and the cooling chamber to mimic the extreme temperature conditions in defense industries.

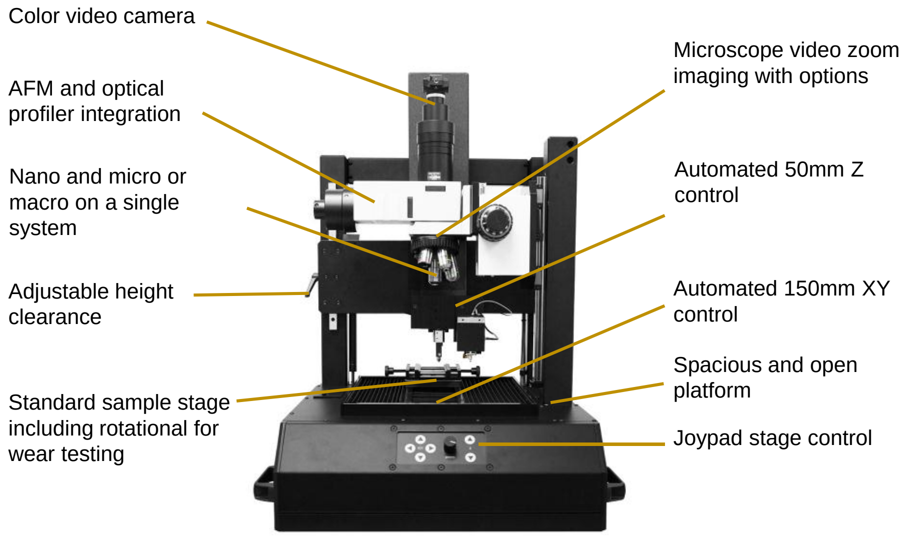
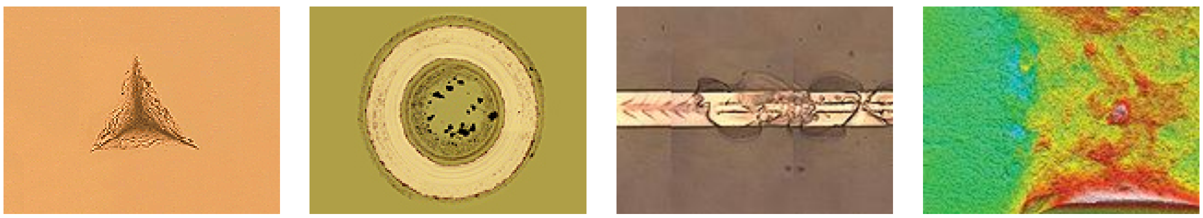


Figure 2. Three-dimensional motorized linear stages. (Photo courtesy of Nanovea Inc.)

The nano-mechanical testing equipment has attracted attentions from both the academia and the defense industry by demonstrating following key capabilities: (1) load-bearing testing: to evaluate load-bearing stability under a broad range of loading regimes; (2) friction and wear testing: to test friction coefficient and wear resistance under severe conditions; (3) adhesion performance testing: to assess the adhesion properties (e.g. critical loads) of coatings, providing characterization of the abrasion resistance of materials; (4) indentation testing: to accurately and precisely measure hardness and elastic modulus of nanostructured materials; (5) lubrication testing: to test lubricity of self-lubrication materials; (6) atomic force microscope (AFM) imaging: to observe the 3D topographies of the sample surface at a high resolution. The key capabilities of the nano-mechanical testing equipment is shown in Figure 3.



(a) (b) (c) (d)

Figure 3. Capabilities of the nano-mechanical testing equipment.
(Images courtesy of Nanovea Inc.)

2. <u>Summary of Research Projects Enabled by This Acquisition</u>

2.1. The research work described in the proposal

The acquired equipment has been used to conduct nano-mechanical tests (such as hardness test and wear and friction resistance test) on TiBw reinforced titanium matrix composites (Proposal Section 6.1. LD-AM of in-situ nano-sized TiBw reinforced TMCs) and Inconel 718 alloys (Section 6.2. ultrasonic vibration assisted LD-AM of nanostructured alloys/composites). The obtained results are necessary foundations to build processing-nanosturcture-property relationships of composites and alloys, providing guidance on fabricating high quality and performance nanostructured materials for defense industries.

In the future, this equipment will be used to conduct nano-scratch testing, nano-indentation testing, and friction testing on nano-sized Al_2O_3 reinforced composite coatings (Section 6.3. LD-AM of nano-sized Al_2O_3 reinforced composite coatings). Obtained results will reflect effects of nano-sized reinforcements on nano-mechanical properties of coatings, thus contributing to developing new ceramic reinforced coatings in metal materials. Due to its capability of providing testing information and identifying types of wear (e.g. fatigue wear, abrasive wear, etc.), the acquired equipment will be used to enable the following tasks (Section 6.4. LD-AM of self-lubrication coatings as well as bulk parts): (1) Investigating effects of different rare earth element based compounds rather than the extensively studied common compounds on self-lubrication properties; (2) Fabrication of multi layers or even bulk self-lubrication parts by using LD-AM; and (3) Better understanding the fundamental mechanism of the self-lubrication phenomena.

2.2. Other research work of interest by DoD

Beyond the proposed research activities, the acquired equipment has also been applied to conducting mechanical tests (such as nano-indentation test and fracture toughness test) on Al_2O_3 and ZrO_2 toughened Al_2O_3. In the future, the acquired equipment will be used for other materials, such as titanium-silver alloys and graphene oxide reinforced Inconel 718, those can be applied to biomedical, high-end engineering, and other DoD desired industries. The obtained results and generated knowledge will provide preliminary results and novel ideas on new proposals writing.