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LLNL-TR-739180

Laser Shot Peening Final Report CRADA No. TC-02059-03

B. C. Stuart, L. Hackel

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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.

Laser Shot Peening

Final Report
CRADA No. TC-02059-03
Date Technical Work Ended: June 24, 2006

Date: September 18, 2006 Revision: 5

A. Parties

This project was a relationship between Lawrence Livermore National Laboratory (LLNL) and Metal Improvement Company, Inc.

The Regents of the University of California
Lawrence Livermore National Laboratory
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B. Project Scope

This was a collaborative effort between The Regents of the University of California, Lawrence Livermore National Laboratory (LLNL) and Metal Improvement Company, Inc. (MIC), to further develop the laser shot peening technology. This project had an emphasis on laser development and government and military applications including DOE's natural gas and oil technology program (NGOTP), Yucca Mountain Project (YMP), F-22 Fighter, etc.

The project consisted of five major tasks and the following five major deliverables:

Deliverable 1. Visits to MIC

LLNL will report on the results of each visit.

MIC will host the visit and provide a report on the meetings.

Daily interactions involved close collaboration on specific projects including laser peening material investigations, weapons applications and Defense Logistics Agency army work.

Deliverable 2. U.S. Army Picatinney Arsenal and Defense Logistics Agency Work

LLNL to provide research and development process deployment concept and representative, non-production test parts of rifles provided by the Army and tested to failure.

MIC - Delivery of treated and tested parts and report on the viability of the research and development process.

Benet labs research on coating adhesion studies lead to specific test program for testing leaf springs for army vehicles. The summary report by Benet labs on the coating adhesion studies is listed under Section F, Reports. Work on Defense Logistics Agency (DLA) Army Rotorcraft program is leading to production laser peening of CH47 Chinook helicopter hinge-pins making the helicopters safer and more reliable.

Deliverable 3. Zimmer Orthopedic Implant Peening Evaluation

LLNL to provide research and development process deployment concept and representative, non-production test parts of medical implants tested to failure.

MIC - Delivery of treated and tested parts and report on the viability of the research and development process.

Zimmer is in product qualification testing for the laser peening fatigue life increase of medical implants. The laser peening treatment of Titanium hip implants has lead to a 100% increase in fatigue strength.

Deliverable 4. Laser Robotics for Peening Fan Blades

LLNL to provide code and research and development processing demonstration of the approach to place peening spots and layers accurately.

MIC - Deployment of upgraded robotics in production peening process.

LLNL robotics expert left the group and MIC continued deployment and development of robotics for production peening processes. MIC has developed robotics for the production peening of commercial Boeing 787 turbine blades using moveable beam technology.

Deliverable 5. Laser Systems Development & Support

LLNL will provide upgraded research and development concepts and prototype hardware for improved production peening systems. This research and development project includes mechanical hardware, electrical power supplies and electronic hardware as well as alignment and maintenance procedures.

MIC - Deployment in a commercial process of research and development concepts developed by LLNL to improve the laser peening system. MIC has developed a transportable laser system with a moveable delivery beam for treatment of large components.

LLNL assisted MIC in the design modifications needed for a third production peening laser system now installed in Earby, UK. Alignment and maintenance procedures for the production laser systems were developed and incorporated into the next MIC production laser builds.

A Final Report will be written by LLNL and MIC within thirty (30) days of the project completion.

This CRADA was originally designated as a twenty-four month project. Two no-cost time extensions were executed for this project, one in 2005 and one in 2006, extending the expiration date to June 24, 2006. All of the major tasks and deliverables were successfully completed.

C. Technical Accomplishments

This CRADA has lead to an R&D 100 award in 2003 for laser peen-forming in addition to the successful deployment of seven production laser systems.

Investigations were performed for corrosion, fatigue benefits, and residual stress curves in laser peened Titanium alloy, Aluminums, and steels. Damage tolerance studies were also performed in carbide steels and Aluminum alloys.

Stress modeling simulations were developed to predict stresses in laser peened materials.

D. Expected Economic Impact

Over 22,000 large core fan blades have been laser peened for aircraft, including the Boeing 777, Airbus A340, Gulfstream 5, and starting the newest aircraft Boeing 787 and 747-8. MIC is beginning to laser peen fan blades for steam turbines used in electric power generation. A single major United States airline has reported savings of Two Hundred Fifty Million Dollars ($250,000,000) per year due to the benefits from this laser peening process. Extrapolated worldwide savings are in the range of billions per year.

D.1 Specific Benefits

Benefits to DOE

Higher levels resistance to stress corrosion cracking and improved standards of quality assurance will greatly benefit DOE's Yucca Mountain Program. Present estimates made by DOE's Yucca Mountain Program Oversight Board are that Laser Peening Technology could save the government as much as One Billion Dollars ($1,000,000,000). Technology was funded by the Office of Fossil Energy's Natural Gas and Oil Technology Partnership for evaluation for improving welds in off-shore drilling platforms. Good initial results have been obtained and work continues by MIC and the oil industry subsequent to DOE funding.

The technology has extended into electric power generation. Laser peening is now applied on a commercial basis to large steam turbine generators to increase reliability and reduce maintenance cost and downtime.

Benefits to Industry

This CRADA will further extend the range of successful applications of laser peening processes for different types of new applications. Broader applications will help develop advanced approaches to improved process performance and quality assurance.

The laser peening process has provided savings of over Two Hundred Fifty Million Dollars ($250,000,000) per year for a single United States airline. Extrapolated worldwide savings are on the order of billions per year for commercial aircraft. Over 22,000 large core fan blades have been laser peened for commercial aircraft and MIC is beginning to laser peen fan blades for steam turbines used in electric power generation.

Laser peened automotive components in particular valves, pistons, crankshafts, connecting rods, and transmission gears have become a high priority in formula 1 racecar advances. As with other advanced technologies, this is expected to transfer to mainline automotive and truck production.

Demonstrated increase in hip implant fatigue strength allows for reduced patient trauma, reduction in replacement operations, and longer lifetime of implants.

E. Partner Contribution

MIC has advanced technology and built production systems for the United States and worldwide market. The partner has interacted extensively with military and the military's OEM contractors. MIC has also worked closely with NASA on using laser peening to extend the fatigue life in friction stir welded components. Currently over fifty projects with specific industrial companies are on-going to deploy the technology into applications.

F. Documents/Reference List

Reports

DLA project report – estimated delivery date from Mike Hill, September 2006

Cuellar, Servando D. "Fatigue Crack Growth Applications of Laser Peened Titanium" MASTERS OF SCIENCE THESIS, University of California Davis; 2003

DeWald, Adrian "Measurement and Modeling of Laser Peening Residual Stress in Geometrically Complex Specimens" PhD Thesis, University of California Davis

Chandra, Amitabh A. "Finite Element Based Least Square Surface Fitting for the Contour Method". Masters of Science Thesis, University of California Davis

Demma, Anne G. "An Engineering Model to Predict Deformation due to Laser Peen Forming". Masters of Science Thesis, University of California Davis

Bhoon, Jasleen "Effects of Laser Peening on Residual Stress and Fatigue Life of Al 7049-T73, A-656 Steel and AL5059 Weldments and Ti-6Al-4V". Masters of Science Thesis, University of California Davis

Liu, Kevin "Effects of Laser Peening on Fretting Fatigue of Ti-6Al-4V and Hydrogen Permeation of 316L Stainless Steel Coupons". Masters of Science Thesis, University of California Davis

Lee, Matthew J. "Gage Length, Slit Width, and Repeatability Effects on the Slitting Method". Masters of Science Thesis, University of California Davis

Pistochini, Theresa ; Hill, Michael R. "Fatigue Life Optimization in Laser Peened 7050-T7451 Aluminum and 300M Steel". Masters of Science Thesis, University of California Davis

Mulligan, Chris to Greg Vigilante. "Laser Shock Peening Summary" Benet Labs Memorandum Report, 28 March 2005

Copyright Activity

Rod Lanning, Bill Behrendt, Steve Telford, Mike Taranowski, and Joe Taranowski (now at MIC) developed the controls software for the production laser systems -- "Laser Controls". This software has since been modified by MIC staff and subsequently again by LLNL staff. Modified versions of the software run laser systems at the MIC production facilities and also in the LLNL laser peening development lab.

Subject Inventions

IL-11312, Patent not pursued

IL-11347, Patent pending

IL-11442, Patent pending

IL-11458, Patent not pursued

Background Intellectual Property

LLNL disclosed the following Background Intellectual Property for this project:

U.S. Patent No. 5,689363 (LLNL Docket IL-9644) – *Long-pulse-width Narrow-bandwidth Sold Sate Laser*; issued: 11/18/97; Inventors: C. Brent Dane, Lloyd A. Hackel

U.S. Patent No. 6,198,069 (LLNL Docket IL-10167) - *Laser Beam Temporal and Spatial Tailoring for Laser Shock Processing*; Issued: 3/6/2001 Inventors: Lloyd A. Hackel, C. Brent Dane

U.S. Patent Application No. 09/591,829 (LLNL Docket IL-10483) - *Ablation and Insulation Layer for Laser Peening*; Inventors: Lloyd A. Hackel, John M. Halpin, Fritz Harris

U.S. Patent No. 6,410,884 (LLNL Docket IL-10558) - *Contour Forming of Metals by Means of Laser Peening*; Issued: 6/25/2002; Inventors: Lloyd A. Hackel, Fritz Harris;

U.S. Patent No. 6,423,935 (LLNL Docket IL-10644) - *Identification Marking by Means of Laser Peening*; Issued 7/23/2002; Inventors: Lloyd A. Hackel, C. Brent Dane, Fritz Harris

U.S. Patent No. 6,657,160 (LLNL Docket IL-10756A) - *Laser Peening of Components of Thin Cross-Section*; Issued 12/2/03; Inventors: Lloyd A. Hackel, John Halpin, Fritz Harris

U.S. Patent No. 6,805,970 (LLNL Docket IL-10756B) - *Laser Peening of Components of Thin Cross-Section*; Issued 10/19/04; Inventors: Lloyd A. Hackel, John Halpin, Fritz Harris

U.S. Patent No. 6,670,578 (LLNL Docket IL-10975) - *Pre-loading of Components During Laser Peenforming*; Issued 12/30/03; Inventors: Lloyd A. Hackel, John Halpin, Fritz Harris

Metal Improvement Company, Inc. licensed the above Background Intellectual Property under LLNL Case No. TL01382-0.0.

Metal Improvement Company, Inc. has not expressed an interest in licensing the Background Intellectual Property listed below.

IL-10832, Patent not pursued

IL-10833, Patent not pursued

IL-10927, Patent not pursued

IL-10990, Patent not pursued

IL-10988, Patent not pursued

IL-11081, Patent not pursued

Metal Improvement Company, Inc. did not disclose any Background Intellectual Property for this project.

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.

Lloyd Hackel 10/27/06

Lloyd Hackel, Vice President for Advanced Technologies — Date
Metal Improvement Company, Inc.

Brent C. Stuart 12/12/06

Brent C. Stuart, LLNL Principal Investigator — Date
Lawrence Livermore National Laboratory

Karena McKinley 12/15/06

Karena D. McKinley, IPAC Director — Date
Lawrence Livermore National Laboratory

Attachment I – Final Abstract

Laser Shot Peening

Final Abstract (Attachment I)
CRADA No. TC-02059-03
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E. Project Dates

.January 24, 2003 to June 24, 2006