REPORT DOCUMENTATION PAGE

Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
29-09-2016	Final Report	15-Aug-2015 - 14-Aug-2016

4. TITLE AND SUBTITLE
Final Report: Non-Contact Optical Metrology Instrumentation for Failure Characterization of Transparent Armor Materials

5a. CONTRACT NUMBER
W911NF-15-1-0357

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)
66754-EG-RIP.1

12. DISTRIBUTION AVAILIBILITY STATEMENT
Approved for Public Release; Distribution 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
This grant was to acquire instrumentation for investigating failure of novel transparent materials. Specifically, a non-contact surface profiling instrument to perform quantitative microscopy of fracture surfaces through post-mortem analyses and a digital camera capable of recording the so-called 4D light-field information to interrogate different layers of a previously recorded image.

15. SUBJECT TERMS
optical metrology, mechanical failure, transparent materials

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Hareesh Tippur
UU	UU	UU	UU		19b. TELEPHONE NUMBER 334-844-3327

Report Title

Final Report: Non-Contact Optical Metrology Instrumentation for Failure Characterization of Transparent Armor Materials

ABSTRACT

This grant was to acquire instrumentation for investigating failure of novel transparent materials. Specifically, a non-contact surface profiling instrument to perform quantitative microscopy of fracture surfaces through post-mortem analyses and a digital camera capable of recording the so-called 4D light-field information to interrogate different layers of a previously recorded image.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

F. G. Tatnall Award, June 2016, Society for Experimental Mechanics

Graduate Students

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Post Doctorates

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Faculty Supported

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Under Graduate students supported

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period:	0.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:......	0.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:......	0.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):......	0.00
Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:......	0.00
The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense	0.00
The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:......	0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

see attachment

Technology Transfer

Project Summary - Grant # 66754-EG-RIP (W911NF-15-1-0357)
(Reporting Period: Aug, 2015 – Aug 14, 2016)

Non-Contact Optical Metrology Instruments for Failure Characterization of Transparent Armor Materials

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Objective

This grant was to acquire instrumentation for investigating failure characterization of novel transparent materials. Specifically, a non-contact surface profiling instrument to perform quantitative microscopy of fracture surfaces through post-mortem analyses and a digital camera capable of recording the so-called 4D light-field information to interrogate different layers of a previously recorded image.

Approach

The first item namely a non-contact surface profiler is suitable for quantifying fracture surface morphology and post-mortem analyses that includes crack pinning, deflection, cavitation, and phase inversion mechanisms of various transparent materials. The second item is intended to extend the optical technique of Digital Gradient Sensing to study failure evolution in transparent solids by interrogating different layers of a 3D transparent solid subjected to mechanical loads.

Relevance to Army

Transparent armor materials offer unusual technological challenges due to the nature of requirements placed on them. A transparent armor material needs to have superior stiffness, strength, toughness, and/or thermal stability all the while being optically transparent. Overall reduction of weight of a transparent structure is also of great significance in achieving good agility and maneuverability when used in a transportation vehicle or in personnel gear. In this context, understanding dynamic failure of transparent armor materials in general and high strain rate fracture in particular is important.

Accomplishments for Reporting Period

- Following the approval of the grant the effectiveness of the non-contact surface profiling instrument was investigated using dynamically fractured specimens both, transparent and otherwise. The results were satisfactory for glass-filled transparent composites. However, the depth resolution could not be satisfactorily ascertained for monolithic brittle transparencies. Further, a new faculty colleague in the college of engineering (Industrial and Systems Eng. Department) at Auburn purchased a comparable surface profiler with similar capabilities as part of establishing a surface metrology lab through seed funds and was accessible to the PI. Accordingly, the PI's the priority for the surface profiler was reconsidered relative to other technological developments in the realm of ultrahigh-speed photography, to be further elaborated in the following paragraphs.
- The feasibility of a 4D light field camera originally proposed by the PI was further evaluated following the approval of the grant. The spatial resolution of the plenoptic

camera system commercially available at the moment was found inadequate due to micro lens arrays used and large amounts data processing necessary. Further, the camera system was found limited to quasi-static measurements. On the contrary, more recent technological advances have occurred in the ultrahigh-speed digital camera technology involving a single imaging sensor with high data throughput. Accordingly, the appropriateness of the 4D light field camera was reconsidered and weighed relative to the needs of a recent ARO grant (proposal # 68721-EG; W911NF-16-1-0093: 'Dynamics of Crack-Interface Interaction in Layered Transparencies: An Experimental Investigation using Novel Optical Techniques').

- After discussing the pros and cons of the above situations with the program manager and appropriate personnel at Auburn University, a request to change the equipment to be purchased was made. The revised item was a Kirana model 05 single sensor ultrahigh-speed camera capable of nanosecond exposure and high framing rate (up to 5M frames per sec). However, the funds available from this grant was insufficient to purchase the item and therefore residual funds from ARO funded research instrumentation grant W911NF-15-1-0295 (approx. $46K) along with approx. $30K matching funds from Auburn University were used to secure Kirana model 05 ultrahigh-speed camera.
- The newly acquired ultrahigh-speed digital camera funded by this grant was recently installed in the PI's laboratory and is currently operational. The camera unit has been tested with both polymeric and ceramic specimens under impact loading conditions. A few select results from the inertial loading leading to crack initiation and growth in a wedge loaded polycarbonate sheet are shown in Figure 1 and 2 as an example. The acrylic sheet had a pre-cut V-notch and loaded using a Hopkinson pressure bar with a matching loading tip (Figure 1). The faces of the notch were dynamically loaded to initiate a mode-I crack at the tip and measure in-plane orthogonal stress gradients (Figure 2) in horizontal and vertical directions simultaneously at 500,000 frames per second.

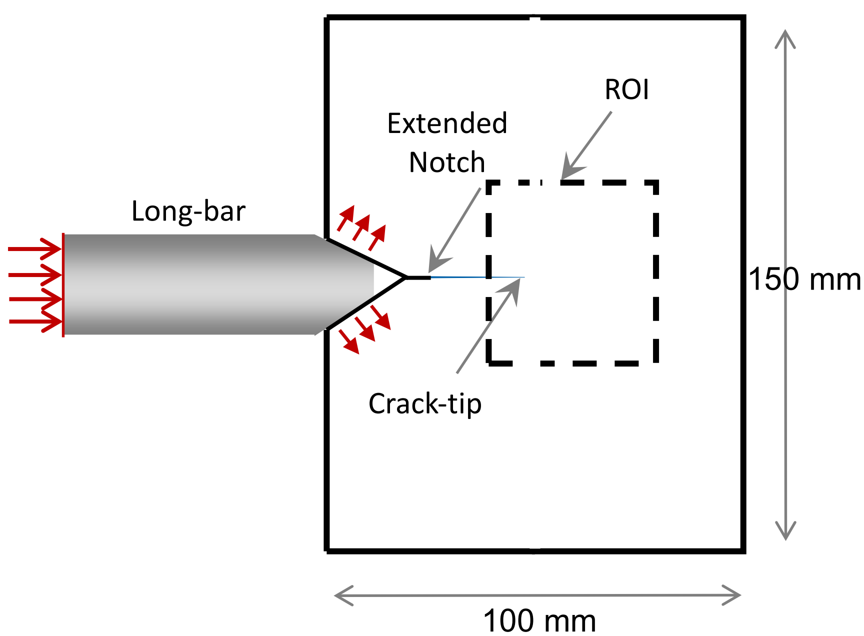

Figure 1

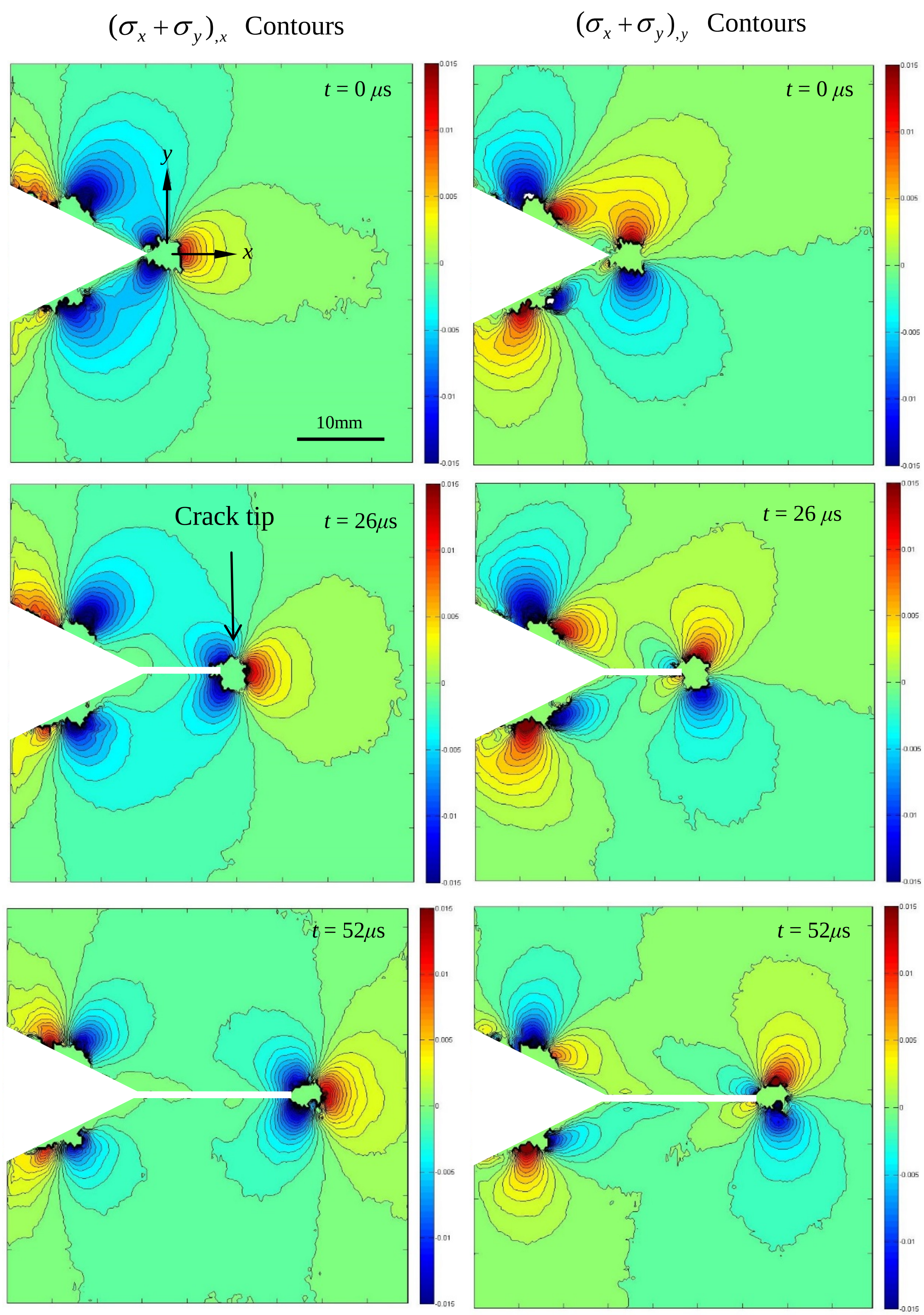

Figure 2. Mode-I stress gradients (contour interval = 1×10^{-3} rad) of $(\sigma_x + \sigma_y)$ in the *x*- and *y*-directions for a polycarbonate recorded at 500,000 fps. (t = 0 corresponds to crack initiation)

Collaborations and Technology Transfer

- Nothing to report yet.

Resulting Journal Publications during Reporting Period

- Nothing to report yet.

Graduate Students Involved During Reporting Period

- N/A (Instrumentation Grant)

Awards, Honors and Appointments

- F. G. Tatnall Award, June 2016, Society for Experimental Mechanics