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14. ABSTRACT
A high-speed infrared (IR) imaging system with appropriate microscope optics has been acquired and calibrated for radiation and temperature measurements in deformation processing and material removal processes. The imaging system has been incorporated into a plane strain deformation process system for metals, enabling systematic measurement of temperature fields in the process zone. Concurrent characterization of strain and strain rate fields in the process zone using high-speed visible imaging coupled with Particle Image Velocimetry; and energy and friction using force measurements is feasible in this 2-D process system. Some measurements planned in the near

15. SUBJECT TERMS
deformation processing, machining, temperature measurement, infrared imaging, microstructure, plastic flow

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Report Title

Final Report: High-Speed Infrared Imaging System for Advanced Metals Processing

ABSTRACT

A high-speed infrared (IR) imaging system with appropriate microscope optics has been acquired and calibrated for radiation and temperature measurements in deformation processing and material removal processes. The imaging system has been incorporated into a plane strain deformation process system for metals, enabling systematic measurement of temperature fields in the process zone. Concurrent characterization of strain and strain rate fields in the process zone using high-speed visible imaging coupled with Particle Image Velocimetry; and energy and friction using force measurements is feasible in this 2-D process system. Some measurements planned in the near future on the Purdue metals processing testbed are described. When fully implemented in the coming months, the combination of measurements will provide unprecedented insight into microstructure and crystallographic texture development in metals processing and wear, and of the interactive effects of strain, strain rate and temperature on microstructure, texture, and flow instabilities.

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

Since this is a DURIP grant that resulted in equipment acquisition only in August 2014, there no papers to report yet. We anticipate the first publications emerging from the use of this equipment to be submitted in february 2015.

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

W. Dale Compton, co-PI, was awarded the 2014 George E. Pake Prize by the American Physical Society (APS) in March. The citation reads - "For exemplary leadership of corporate automotive R&D at a critical time for the industry and for important individual achievements in experimental solid state physics."

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Ho Yeung	0.00
Dinakar Sagapuram	0.00
FTE Equivalent:	**0.00**
Total Number:	**2**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Srinivasan Chandrasekar	0.00	
W Dale Compton	0.00	Yes
Kevin Trumble	0.00	
Michael Sangid	0.00	
John Sullivan	0.00	
FTE Equivalent:	**0.00**	
Total Number:	**5**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED	Discipline
Evan Barta	0.00	Industrial Engineering, Mathematics
FTE Equivalent:	**0.00**	
Total Number:	**1**	

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
James Mann	0.00
FTE Equivalent:	**0.00**
Total Number:	**1**

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Problem statement

The high speed infrared (IR) imaging system that has been acquired via the DURIP award is an FLIR SC 8303 imaging camera from FLIR Systems. In conjunction with microscopic optics, it has been incorporated into an experimental testbed for studying deformation processing, material removal processes and sliding wear. The plane strain testbed has capabilities for simultaneously imaging the deformation zone in the visible wavelength and for analyzing this flow data using Particle Image Velocimetry to obtain strain, strain rate fields and various path lines of flow.
Thus concurrent information about deformation and temperature fields can be obtained in situ, enabling unprecedented insights to be gathered about the interactive effects of deformation, flow and temperature, on microstructure and mechanical response of the material in processing.

The IR system has been calibrated and the design of the microscope optics completed. The system has been incorporated into the plane strain process testbed. The first results should be obtained by late December or early Jan. 2015.

We describe below some of the topics that will be studied in the next 9-12 months, to complement visible imaging work already in progress. Preliminary findings are summarized.

Summary of Main Results and Findings

a) Surface deformation processing and flow phenomena in sliding

Using high-resolution, in situ imaging of a hard, wedge-shaped indenter sliding against metals, we are exploring the deformation and flow fields developed at surfaces. This system represents the unit-interaction in various surface conditioning processes such as surface mechanical grinding, burnishing, shear spinning and surface attrition. It is also representative of unit asperity interactions in sliding. We have quantified the strain and strain rate fields developed in the workpiece (WP) surface in both single- and multi-pass deformation. The strain accumualtion has been characterized as a function of deformation passes at high resolution. Correlations with microstructure and microstructure phenomena will be established, once temperature field data becomes available from the IR system. This will provide new quantitative insights into mechanisms of structure refinement, dynamic recrystallization and texture development.

The study has already demonstrated a new mechanism for particle formation in deformation processing, and in delamination wear. Damage to the residual surface of the WP is caused by the occurrence of folds on the free surface of the prow-shaped region ahead of the wedge. This damage manifests itself as shallow crack-like features and surface tears, which are inclined at very acute angles to the surface. The transformation of folds into cracks, tears and particles is directly captured. Notably, a single sliding pass is sufficient to damage the surface, and subsequent passes result in the generation of platelet-like wear particles. Tracking the folding process at every stage from surface bumps to folds to cracks / tears/ particles ensures that there is no ambiguity in capturing the mechanism of defect formation and wear. Because fold formation and consequent delamination are quite general, these findings have broad for design of surface generation and conditioning processes, and for sliding wear.

The temperature measurements that will be carried out in the near future will enable an exploration of this phenomenon at high sliding speeds, wherein thermal effects are likely to become quite important.

b) Flow instabilities in the cutting of metals and their control

We are investigating the occurrence of various flow instabilities at surfaces in the cutting of metals. Plastic flow instability in the form of strain localized to (shear) bands often limits the high strain-rate deformation capacity of metals. Although there have been significant advances in the fundamental understanding of the problem through theoretical and experimental methods, quantitative knowledge of the deformation conditions inside the shear band and related microstructure-property relations are scarce. We have used metal cutting as a framework to impose controlled shear deformation at high rates (1000-100000 s-1) and probe the shear banding phenomenon in titanium and its alloys. Shear band strains are estimated by measuring the relative slip between neighboring segments of the chip and the layer (shear band) width. Electron microscopy of over 50 shear bands shows that the bands are typically thin, 4-6 μm. The shear strain measurements show the strain to be quite uniform along the band, and in the range of 15-20. These strains are among the highest reported in the literature. The strain rate in the band is over an order higher than the imposed rate. These large strain and strain-rate conditions result in nanocrystalline (100 nm) and nanotwinned structures in the band. The shear band is thus manifested by a higher hardness and lower recrystallization temperature compared to the adjacent, low-strained regions. The shear band strain increases with increasing deformation rate, reaching values as high as 40. Temperature measurements soon to be carried out will help establish the temperature field in and around the bands. This will provide clear insights into how the bands are triggered.

Another type of flow instability triggers the propagation of ductile failures from the WP surface in cutting. This is being studied in a model system of a brass workpiece loaded against a 2-D wedge indenter, wherein the spectrum of sliding and cutting regimes is accessed. At large negative rake angles, the flow is steady with a prow of material forming ahead of the indenter. There is no material removal and a uniformly strained layer develops on the workpiece surface – the pure sliding regime. When the rake angle is less negative, a flow instability occurs, triggered by formation of a crack on the prow free surface with material removal ensuing – the cutting regimes. The prow slope at onset of instability is remarkably constant. The common chip morphologies such as discrete particle, segmented chip and continuous chip with mesoscale roughness, are shown to arise from a universal mechanism involving propagation of this crack, but to different distances from the prow surface. The simple shear deformation underlying continuous chip formation also shows an instability - small-angle oscillations of the deformation zone – linked to the prow-crack. As the work transitions to higher speeds, knowledge of the temperature fields will become critical to see how this type of flow instability is affected.

Examination of these flow instabilities suggests that the unconfined nature of flow in the vicinity of surfaces plays a key role in the occurrence of these instabilities. Consequently, the onset of these instabilities could potentially be delayed by converting the usual cutting/sliding processes to a confined deformation type process. Various strategies are being examined for this purpose. A constrained (hybrid) cutting-deformation process has already shown promise in suppressing flow instabilities in deformation processing and machining of hcp metals such as Mg and Ti alloys.

A more fundamental understanding of these phenomena will be obtained once the IR system begins to yield temperature field data complementary to the deformation field data. Another outcome of the study will be the availability of a general purpose experimental approach for simultaneous measurement of deformation and temperature fields over large fields of view in processing.

References

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Technology Transfer