

Georgia Tech Sponsored Research

Project	E-25-6B5
Project director	Jasiuk Iwona
Research unit	Mech Engr
Title	Nanolaminates and Microlaminates: Modeling and Characterization
Project date	3/14/2003

Thelma Woods

~~69~~
E-25-6B5

To: Iwona Jasiuk
Subject: RE: My Progress Report

Per Dr. Jasiuk
#1

Hi, Dr. Jasiuk

Yes, I will distribute hard copies to sponsor. Please identify the Project number for me.

Thanks

-----Original Message-----

From: Iwona Jasiuk [mailto:iwona.jasiuk@me.gatech.edu]
Sent: Wednesday, September 05, 2001 3:48 PM
To: ocareports@oca.gatech.edu
Cc: iwona.jasiuk@me.gatech.edu
Subject: Fwd: My Progress Report

SEP 05 2001

Rpt. attached

Hello,

Here is a copy of my progress report for the AFOSR. I did send it by e-mail but I understand that I need to submit hard copies also. Can you assist me with this process?

Thanks,

Iwona

Prof. Iwona Jasiuk
The GWW School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0405, USA
Phone: (404) 894-6597
Fax: (404) 894-0186
E-mail: iwona.jasiuk@me.gatech.edu
http://www.me.gatech.edu/me/people/academic.faculty/Jasiuk_Iwona.html

>Date: Sat, 1 Sep 2001 23:14:14 -0400
>From: Iwona Jasiuk <iwona.jasiuk@me.gatech.edu>
>To: Hahn Thomas Civ AFRL/AFOSR <thomas.hahn@afosr.af.mil>
>Cc: iwona.jasiuk@me.gatech.edu
>Subject: My Progress Report
>User-Agent: Internet Messaging Program (IMP) 2.3.7-cvs
>X-Originating-IP: 66.156.61.61

>Dear Tom,

>
>Enclosed please find my progress report. One original and a copy will be placed in the mail on Tuesday, September 4. I apologize for a delay with sending you a hard copy.

06-Sept-01 JW

E-25-6B5
#1

>With best regards,
>
>Iwona
>
>*****
>Prof. Iwona Jasiuk
>The GWW School of Mechanical Engineering
>Georgia Institute of Technology
>Atlanta, GA 30332-0405, USA
>Phone: (404) 894-6597
>Fax: (404) 894-0186
>E-mail: iwona.jasiuk@me.gatech.edu
>*****
>
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Thelma Woods

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Sent: Wednesday, September 05, 2001 3:48 PM
To: ocareports@oca.gatech.edu
Cc: iwona.jasiuk@me.gatech.edu
Subject: Fwd: My Progress Report



afosr-progress-sep1-jasiuk.doc...

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Iwona

SEP 05 2001

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Phone: (404) 894-6597
Fax: (404) 894-0186
E-mail: iwona.jasiuk@me.gatech.edu
http://www.me.gatech.edu/me/people/academic.faculty/Jasiuk_Iwona.html

>Date: Sat, 1 Sep 2001 23:14:14 -0400
>From: Iwona Jasiuk <iwona.jasiuk@me.gatech.edu>
>To: Hahn Thomas Civ AFRL/AFOSR <thomas.hahn@afosr.af.mil>
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Thelma Woods

From: Iwona Jasiuk [iwona.jasiuk@me.gatech.edu]
Sent: Wednesday, September 05, 2001 4:48 PM
To: Thelma Woods
Cc: iwona.jasiuk@me.gatech.edu
Subject: RE: My Progress Report

Thelma,

Here is the information:
AFOSR grant F49620-01-1-0131 (Dr. T. Hahn is the program monitor).
The GT number is E25-6B5

SEP 06 2001

Iwona

At 03:46 PM 9/5/01 -0400, you wrote:

> Hi, Dr. Jasiuk
>
> Yes, I will distribute hard copies to sponsor. Please identify the
Project
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> Thanks
>-----Original Message-----
>From: Iwona Jasiuk [mailto:iwona.jasiuk@me.gatech.edu]
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>*****
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>>Georgia Institute of Technology
>>Atlanta, GA 30332-0405, USA
>>Phone: (404) 894-6597
>>Fax: (404) 894-0186
>>E-mail: iwona.jasiuk@me.gatech.edu
>>*****
>>
>>



**Georgia Institute
of Technology**

Office of Sponsored Programs
Research Administration, Compliance,
Training, and Technologies (ReACTT)
Atlanta, Georgia 30332-0420 U.S.A.
PHONE 404-894-6944
FAX 404-894-5285

September 6, 2001

In reply refer to: E-25-6B5

**Dr. Thomas Hahn
Air Force Office of Scientific Research
801 N. Randolph Street, Room 732
Arlington, VA 22203-1977**

**Subject: Performance Report
Project Director(s): Dr. Iwona Jasiuk
Telephone No.: (404) 894-6597
Contract No.: F49620-01-1-0131
Prime No.: N/A
"NANOLAMINATES AND MICROLAMINATES: MODELING AND
CHARACTERIZATION"
Period Covered: 15-DEC-2000 – 30-AUG-2001**

The subject report is forwarded in conformance with the contract/grant specifications.

Should you have any questions or comments regarding this report(s), please contact the Project Director or the undersigned at 404-894-4763.

/tw

Sincerely,

Thelma Woods
Customer Service Representative

**Distribution:
Addressee: 2 copies
cc: ONR-RR**

E-25-6B5
#1

A PROGRESS REPORT

for the project entitled

**Nanolaminates and Microlaminates:
Modeling and Characterization**

Submitted to

Dr. Thomas Hahn

AFOSR

by

Georgia Institute of Technology

Principal Investigators:

Iwona Jasiuk* and W. Jack Lackey**

The G.W.W. School of Mechanical Engineering

Georgia Institute of Technology, Atlanta, GA 30332-0405

*iwona.jasiuk@me.gatech.edu, phone: (404) 894-6597, fax (404) 894-0186

**jack.lackey@me.gatech.edu, phone: (404) (404)894-0573, fax: (404) 894-9342

September 1, 2001

E-25-6 B5
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A PROGRESS REPORT

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**Nanolaminates and Microlaminates:
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Principal Investigators:

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**jack.lackey@me.gatech.edu, phone: (404) (404)894-0573, fax: (404) 894-9342

September 1, 2001

2. OBJECTIVES

The objective of this research is to develop micromechanics models of laminated materials at different scales and verify the models experimentally. This research will permit optimization of properties of ceramic/ceramic and metal/ceramic laminates. This research will involve the following:

- Macroscale laminate modeling using classical continuum mechanics theories
- Microlaminate modeling using non-classical theories, such as strain gradient theories
- Nanoscale laminate finite element modeling accounting for discrete microstructures
- Fabricate C/SiC and Re/SiC laminates with layer thickness spanning three length scales (mm, μm , nm)
- Measure mechanical properties and characterize microstructure of individual layers and laminates at all three length scales
- Verify analytical results with experimental measurements across length scales
- Utilize analytical, experimental and characterization results to optimize processing parameters in order to achieve preferred microstructures
- Design laminates having optimum properties by tailoring layer thicknesses and microstructures.

The long term objective is to advance modeling of laminates at micron and nanoscales in order to permit development of novel laminates possessing superior mechanical properties. Such materials will be useful in structural and electronic aerospace applications. Superior properties will be realized as a result of the capability of creating novel materials by virtue of our ability to control layer geometries (orientation) and thickness, including at the nanoscale where superlattice effects should contribute. Such laminates can be fabricated via laser-jet chemical vapor deposition (LCVD) method.

3. STATUS OF EFFORT

During the last year we addressed the following items:

- Macroscale laminate modeling using classical continuum mechanics theories
- Fabricate C/SiC laminates: We have made progress in two areas--LCVD growth of small cylindrical carbon specimens (ie, fibers) and small rectangular slabs of carbon. Scanning electron microscopy shows both materials to have a good (ie, dense) microstructure. The growth of these materials is reported in Dan Jean's Ph. D. thesis and a paper that has been submitted to the Carbon Journal for publication.

In addition we made a progress in the following areas:

- Microlaminate modeling using non-classical theories. We conducted preliminary calculations using couple stress theory. These calculations included the prediction of couple stress constants for materials with microstructures. In addition we explored the new theory, developed by Zubelewicz (2001), capable of identifying cavitation mechanisms in power-law creeping materials. This is a continuum theory, which has a micromechanics-based flow rule. Our preliminary evaluation shows a great promise for modeling of metals, and interface fracture.
- We did some preliminary measurements of material properties using our nanoindenter.

4. ACCOMPLISHMENTS/NEW FINDINGS

This is research in progress. Our research highlights include fabricating C/SiC samples and preliminary modeling as discussed in item 3. These two items follow closely the goals set in our proposal. Additional theory addressing cavitation is new and has a potential to be very useful and complementary to non-classical continuum approaches. It may become very useful for modeling of metals in general.

5. PERSONNEL SUPPORTED

Two faculty members: Drs. Iwona Jasiuk and Jack Lackey were involved in this project. Two graduate students Ji Eun Park and Dan Jean were supported from this grant.

6. PUBLICATIONS

Three journal papers were submitted for publication. These are:

D. Jean and J. Lackey, "Carbon Fiber Growth Kinetics and Thermodynamics Using Temperature Controlled LCVD," *Carbon Journal*, submitted.

J. E. Park, I. Jasiuk and A. Zubelewicz, "Stresses and Fracture along the Chip/Underfill Interface in Flip Chip Assemblies," *J. Electronic Packaging*, submitted.

F. Bouyge, S. Boccara, I. Jasiuk, and M. Ostoja-Starzewski, "Prediction of couple stress moduli for orthotropic composites," *European Journal of Solids, A*, in revision.

7. INTERACTIONS/TRANSITIONS

- a. participation in two conferences where nanotechnology papers were presented.
- b. collaboration with Dr. Aleksander Zubelewicz (since the beginning of a project)
- c. collaboration with Dr. Aleksander Zubelewicz (since the beginning of a project)

Dr. Aleksander Zubelewicz, Ph.D., Senior Reliability Engineer
Wireless Systems Subscriber Group, SPS, Mail Drop: OE314, Motorola
6501 William Cannon Dr. West, Austin, TX 78735

Phone: (512) 895-7667; Email: Alek.Zubelewicz@motorola.com; Fax: (512) 895-7835

Nature of collaboration: Modeling of layered materials from micrometers to nanometers.

Developments of analytical models for layered systems. Determination of stresses in layered composites using analytical or computational approaches. Development of micromechanics-based fracture criterion at bi-material interfaces.

Applications: Reliability of MEMS. Design of reliable electronic packaging devices

8. NEW DISCOVERIES, INVENTIONS, OR PATENT DISCLOSURES

None.

9. HONORS/AWARDS

None.

Thelma Woods

E-25-6B5

#2

From: Iwona Jasiuk
Sent: Wednesday, September 04, 2002 5:33 PM
To: ocareports
Cc: Thelma Woods
Subject: Progress report



afosr-progress-sep
1-02-jasiuk2...

Thelma,

I enclose the file with my Progress Report for the AFOSR, which was due on September 1, 2002.

The information on the grant is as follows:

AFOSR grant F49620-01-1-0131 (Dr. B.L. Lee is the program monitor). The GT number is E25-6B5.

* Please note that I already sent this report to the sponsor via e-mail on September 1, 2002.

Can you send them a hard copy?

The address is:

B. L. ("Les") Lee
Program Manager for Mechanics of Materials & Devices
Air Force Office of Scientific Research
801 N. Randolph Street, AFOSR/NA, Room 956
Arlington, VA 22203-1977
Phone: 703 696 8483
FAX: 703 696 8451
email: ByungLip.Lee@afosr.af.mil or Les.Lee@afosr.af.mil

Thank you,

Iwona

Prof. Iwona Jasiuk
The GWW School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0405, USA
Phone: (404) 894-6597
Fax: (404) 894-0186
E-mail: iwona.jasiuk@me.gatech.edu
http://www.me.gatech.edu/me/people/academic.faculty/Jasiuk_Iwona.html

9/4/02 @ 4:20pm

9/5/02 JW



September 5, 2002
Reply to: E-25-6B5

Dr. B.L. Lee
Program Manager for Mechanics of Materials
& Devices
Air Force Office of Scientific Research
801 N. Randolph Street, AFOSR/NA, Room 956
Arlington, VA 22203-1977

Subject: Performance Report

Project Director(s): Drs. Iwona Jasiuk and W. Jack Lackey

Telephone No.: (404)894-6597/0573

Contract No.: F49620-01-1-0131

Prime No.: N/A

**“NANOLAMINATES AND MICROLAMINATES: MODELING
AND CHARACTERIZATION”**

Period Covered: 01-September-2001 – 30-August-2002

The subject report is forwarded in conformance with the contract/grant specifications.

Should you have any questions or comments regarding this report(s), please contact the Project Director or the undersigned at 404-894-4763.

/tw

Sincerely,

Thelma Woods
Customer Service Representative

Distribution:
Addressee: 1 copy

E-25-6B5
#2

A PROGRESS REPORT

for the project entitled

**Nanolaminates and Microlaminates:
Modeling and Characterization**

Submitted to

Dr. B. L. ("Les") Lee

AFOSR

by

Georgia Institute of Technology

Principal Investigators:

Iwona Jasiuk* and W. Jack Lackey**

The G.W.W. School of Mechanical Engineering

Georgia Institute of Technology, Atlanta, GA 30332-0405

*iwona.jasiuk@me.gatech.edu, phone: (404) 894-6597, fax (404) 894-0186

**jack.lackey@me.gatech.edu, phone: (404) (404)894-0573, fax: (404) 894-9342

September 1, 2002

2. OBJECTIVES

The objective of this research is to develop micromechanics models of laminated and particle reinforced composite materials at different scales and verify the models experimentally. This research will permit optimization of properties of ceramic/ceramic and metal/ceramic laminates and particle reinforced polymer matrix composites. This research will involve the following:

- Macroscale laminate and particulate composites modeling using classical continuum mechanics theories and micromechanics,
- Microlaminate and microparticle reinforced composites modeling using non-classical theories, such as micropolar or strain gradient theories,
- Nanoscale laminate and nanoparticle composites modeling accounting for discrete microstructures of constituents,
- Fabricate C/SiC and Re/SiC laminates with layer thickness spanning three length scales (mm, μm , nm); fabricate particle reinforced composites consisting of cobalt particles and polymer matrix (polystyrene, polyethylene and rubber) with particle diameters spanning two scales (μm , nm),
- Measure mechanical properties and characterize microstructure of individual layers and laminates at all three length scales, and polymer matrix composites at two scales,
- Verify analytical results with experimental measurements across length scales,
- Utilize analytical, experimental and characterization results to optimize processing parameters in order to achieve preferred microstructures
- Design laminates and particle reinforced composites having optimum properties by tailoring layer thicknesses and microstructures.

The first long term objective is to advance modeling of laminates at micron and nanoscales in order to permit development of novel laminates possessing superior mechanical properties. Such materials will be useful in structural and electronic aerospace applications. Superior properties will be realized as a result of the capability of creating novel materials by virtue of our ability to control layer geometries (orientation) and thickness, including at the nanoscale where superlattice effects should contribute. Such laminates can be fabricated via laser-jet chemical vapor deposition (LCVD) method.

The second long term objective involves the advancement in modeling of particle reinforced polymer matrix composite materials with diameters of nanometer size and to develop processing techniques that will yield composites with nanometer size reinforcement possessing superior properties. The interest is in identifying how properties are change when reinforcement decreases to nanosize. Several types of polymer matrix are being explored ranging from brittle, semibrittle to ductile.

NOTE: The original proposal included the investigation of laminated systems (i.e. first objective) while in the last year we extended the research to include polymer matrix nanoparticle reinforced composites.

3. STATUS OF EFFORT

During the last year we addressed the following items:

- Additional macroscale laminate modeling using classical continuum mechanics theories,
- Macroscale modeling and microscale modeling of particle reinforced composite materials
- Fabrication of C/C and C/SiC laminates, testing of local properties using nanoindentation technique,
- Fabrication of nanoparticle reinforced polymer matrix composites. We made progress in making nanocomposites with polystyrene matrix and cobalt particles. We also did preliminary testing of local properties using nanoindentation technique and macroscopic properties of such composites using DMA.

In addition we made a progress in the following areas:

- Microlaminate and particle reinforced composites modeling using non-classical theories, more specifically couple stress theory. We developed the methodology to predict couple stress constants of composite materials with classical constituents.
- In addition we used a recently developed theory (Zubelewicz, 2001), capable of identifying cavitation mechanisms in power-law creeping materials. This is a continuum theory, which has a micromechanics-based flow rule. We solved the planar elasticity problem involving a concentrated force acting on a half-plane (Flamant problem). This problem is of importance in nanoindentation technique, which relies on measurement of local material properties using very small forces.
- Considerable progress was made in the laser CVD (LCVD) of both carbon and silicon carbide. We have obtained a thorough understanding of the LCVD of carbon layers and have learned how to control the process so that carbon deposits can be made reproducibly. We also have improved our understanding of the LCVD of silicon carbide. This knowledge will assist our reproducible synthesis of C-C, C-SiC and SiC-SiC laminates required for this study.

4. ACCOMPLISHMENTS/NEW FINDINGS

This is research in progress. Our research highlights include fabricating C/SiC laminated samples and nanoparticle polymer matrix composites and preliminary modeling as discussed in item 3. These analysis and fabrication of laminated composite materials follow closely the goals set in our proposal. The investigation of nanoparticle polymer matrix composites is new. Additional theory addressing cavitation is also new and has a potential to be very useful and complementary to non-classical continuum approaches. It is applicable to polymers and metals.

5. PERSONNEL SUPPORTED

Two faculty members: Drs. Iwona Jasiuk and Jack Lackey were involved in this project. Four graduate students Jefferey Jordan, Dan Jean, Scott Bondi and Ryan Johnson were also supported from this grant.

6. PUBLICATIONS

Two papers were published:

M. Jiang, I. Jasiuk, and M. Ostoja-Starzewski (2002), "Apparent elastic and elastoplastic behavior of periodic composites," *International Journal of Solids and Structures*, **39**, 199-212.

F. Bouyge, S. Boccara, I. Jasiuk, and M. Ostoja-Starzewski (2002), "A Micromechanically Based Couple-Stress Model of an Elastic Orthotropic Two-phase Composite," *European Journal of Mechanics/A: Solids*, **21**, 465-481.

Two papers are in press:

Ji Eun Park, I. Jasiuk and A. Zubelewicz, "Micromechanics-Based Interfacial Stress Analysis and Fracture in Electronic Packaging Assemblies," *ASME Journal of Electronic Packaging*, in press.

M. Jiang, I. Jasiuk and M. Ostoja-Starzewski, "Apparent thermal conductivity of periodic two-dimensional composites," *Computational Materials Science*, in press.

C. Duty, R. Johnson, J. Gillespie, A. Fedorov, and W. J. Lackey, "Heat and Mass Transfer Modeling of an Angled Gas-Jet LCVD System," Accepted by *J. Applied Physics*, January, 2002.

D. Jean, C. Duty, R. Johnson, S. Bondi, and W. J. Lackey, "Carbon Fiber Growth Kinetics and Thermodynamics Using Temperature Controlled LCVD," accepted for Publication in *Carbon*, September, 2001.

Ryan Johnson, Scott Bondi, Chad Duty, Daniel Jean, Tarek Elkhatib, and W. Jack Lackey, "Fabrication of Multi-Layered Carbon Structures Using LCVD," Twelfth Annual Solid Freeform Fabrication Symposium, University of Texas at Austin, 61-68, August, 2001.

One journal paper is in revision:

J. E. Park, I. Jasiuk and A. Zubelewicz, "Interfacial Stress Analysis and Fracture of a Bi-material Strip with a Heterogeneous Underfill," *J. Electronic Packaging*, in revision.

Several other papers are in preparation.

7. INTERACTIONS/TRANSITIONS

- a. participation in several conferences where nanotechnology and laminate structure papers were presented, several papers are submitted for presentation at national/international conferences
- b. collaboration with Dr. Aleksander Zubelewicz (since the beginning of a project)
- c. collaboration with Dr. Aleksander Zubelewicz (since the beginning of a project)

Dr. Aleksander Zubelewicz, Ph.D.,
Los Alamos National Laboratory, E-mail: alek@lanl.gov
Formerly at: Wireless Systems Subscriber Group, SPS, Mail Drop: OE314, Motorola
6501 William Cannon Dr. West, Austin, TX 78735

Nature of collaboration:

- Modeling of layered materials, developments of analytical models for layered systems. Determination of stresses in layered composites using analytical or computational approaches. Development of micromechanics-based fracture criterion at bi-material interfaces.

Applications: Reliability of MEMS. Design of reliable electronic packaging devices

- Solution of concentrated force problem including cavitation effects.

Applications: Interpretation of nanoindentation results.

8. NEW DISCOVERIES, INVENTIONS, OR PATENT DISCLOSURES

None.

9. HONORS/AWARDS

None.