

# GATE Center of Excellence at UAB in Lightweight Materials for Automotive Applications

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University of Alabama at Birmingham (UAB), Birmingham, Alabama  
February 28, 2008

Project No: DE-FG26-05NT42620

Program Manager: Dr. Samuel Taylor



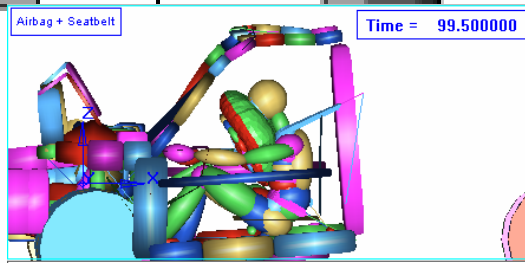
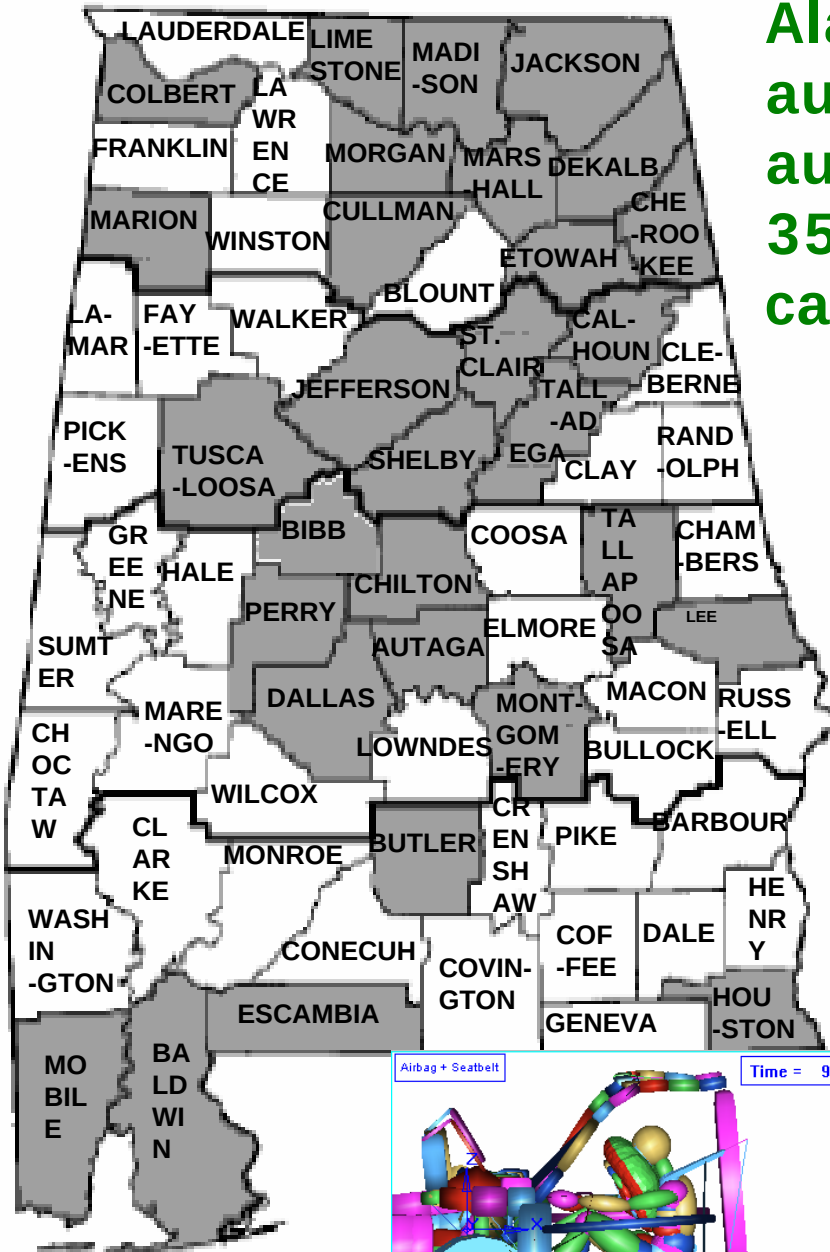
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# Automotive Industry Impact in the State of Alabama

DOE Merit Review  
February 28, 2008

**Alabama has a rapidly growing automotive industry. Since 1993 the automotive sector has created more than 35,000 new jobs and \$6.4 billion in capital investment in Alabama.**

The UAB GATE center is focused on training students in advanced lightweight materials and manufacturing technologies. Recent developments in low-cost composite materials and lightweight castings and fabrication technologies offer excellent potential for design and manufacturing of future generation transportation, including automobiles, mass transit and light, medium and heavy trucks.



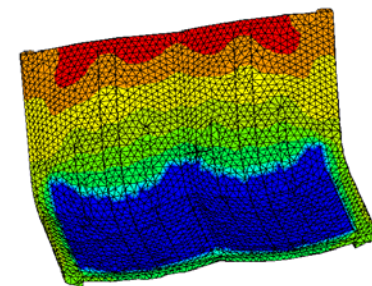
Modeling of crash & protective padding



High speed  
computational facility



Automotive  
castings



Process  
modeling

# Structure of the UAB GATE Center

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## UAB Materials Science & Engineering

- Advanced lightweight composite materials for vehicles
- Automotive Castings

## UAB Civil & Environmental Engineering

Lightweight materials for energy absorbing guard rails and bridge repair/retrofit

## UAB Biomedical Engineering

Crash & injury studies, Studies for protection using lightweight advanced materials

## UAB Mechanical Engineering

High fidelity modeling & simulation of crashes, material process models and structural analysis

## Miles College

- Minority institution partner
- Pipeline to UAB programs & graduate school

## UAB GATE (DOE CENTER OF EXCELLENCE)



## Lawson State, Calhoun & Jeff State Community College

- 2-year automotive degree
- Pipeline to UAB and automotive industry

## Alabama Based Automotive Companies

- Honda, Mercedes, Hyundai, Toyota
- Plastics molders

National Labs & State  
- Oak Ridge  
- ALDOT

## Small Businesses

- Coosa Composites
- Glasforms
- Britt & Co.
- Biomedical Co.

- Goals and Objectives
- Address Previous Review Comments
- Barriers
- Approach
- Performance Measures and Accomplishments
- Publications/Patents
- Collaborations/Interactions
- Plans for Next Fiscal Year
- Summary

## **Overall FCVT Goal**

- **“Development and validation of advanced materials and manufacturing technologies to significantly reduce automotive vehicle body and chassis weight without compromising other attributes such as safety, performance, recyclability, and cost.”**

## **DOE GATE Goal**

- **“To provide a new generation of engineers and scientists with knowledge and skills in advanced automotive technologies.”**

## **The UAB GATE Goals are focused on the above FCVT and GATE goals**

- **Train and produce graduates in lightweight automotive materials technologies**
- **Structure the engineering curricula to produce specialists in the automotive area**
- **Leverage automotive related industry in the State of Alabama**
- **Expose minority students to advanced technologies early in their career**
- **Develop innovative virtual classroom capabilities tied to real manufacturing operations**
- **Integrate synergistic, multi-departmental activities to produce new product and manufacturing technologies for more damage tolerant, cost-effective, and lighter automotive structures.**

## Year 2 Objectives

- Continue to recruit GATE students and enable interdisciplinary research projects
- Consolidate the course structure and continue GATE course offerings that will enable graduate students to be trained in automotive technologies of the future
- Offer virtual classroom experience
- Coordinate and offer three workshops for community colleges and workforce development centers
- Hold Advisory Board meetings
- Tour industry sites

# Approach to Meet Objectives (including targets)

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- Support 3 graduate students/year (two supported by DOE and one cost shared by UAB) with research projects focused on automotive applications
- Support 4 undergraduates each year in automotive related research
- Develop and offer six new automotive related courses (two per year for the first three years) with the potential to impact 20 – 30 students per year
- Influence at least 30 students per year through hands-on workshops
  - Undergraduate students (promote interest in graduate studies)
  - High school students (promote interest in the automotive area)
  - Include a focus on minority students (tap into a larger workforce)
- Interact with industry through Advisory Board Memberships, tours of their facilities, collaboration through the virtual classroom concept, and interaction on research projects (including SBIRs and STTRs)

## Specific Strengths and Weaknesses (Written responses from 3 of 5 reviewers)

- **Specific Strengths**

- “Good work in training students.”
- “This is the first year of the GATE center, and so expectations are to be tempered.”
- “Exceeded objectives in terms of number of students reached -- 150 students reached in 1.5 years.”

- **Specific Weaknesses**

- “It is not clear to me what the technical accomplishments and specific industry collaborations are.”

- **Response to Weaknesses**

- *Technical contributions*

- *Over 25 GATE research papers have been published covering both basic science and application developments in advanced materials. Topics covered include light weighting (a FreedomCAR mission), enhanced structural and functional response, and improved performance.*
- *Specific industry collaborations are covered in the upcoming slides.*

## Specific Recommendations

- Recommendation/Comment:
- Interface with other GATE centers to see what works and what doesn't.
- Response/Action:
- We paid close attention to the sister GATE center presentations in the June 2007 review and will be scheduling individual visits in Spring and Summer 2008.
- Recommendation/Comment:
- UAB has a long laundry list of things to be done, but presumably not all of these are performed using the somewhat restricted budget.
- Response/Action:
- The focus of our program is in advanced lightweight materials. All participants in our multi-discipline program support the primary focus. GATE support is leveraged with automotive related funding from other sources. The technical plan and student recruitment is well-aligned with the research projects.

## Specific Recommendations

- Recommendation/Comment:
- If students leaves GATE after 1.5 years, is their future research oriented to the DOE efficiency & materials goals?
- Response/Action:
- Absolutely. The GATE student's thesis/dissertation is well-defined prior to them coming off of GATE funding after the allowed time period.
- Recommendation/Comment:
- If not, should GATE support fewer for longer, to focus on these areas? This is for consideration, not a firm recommendation.
- Response/Action:
- Our initial model was designed to maximize the number of students trained. However, we have determined that longer duration student support may be desirable for research areas with limited funding. We have revised our approach for specific cases.
- Recommendation/Comment:
- Good direct exchange between the students and ORNL.
- Response/Action:
- Thank you. We will continue this interaction.

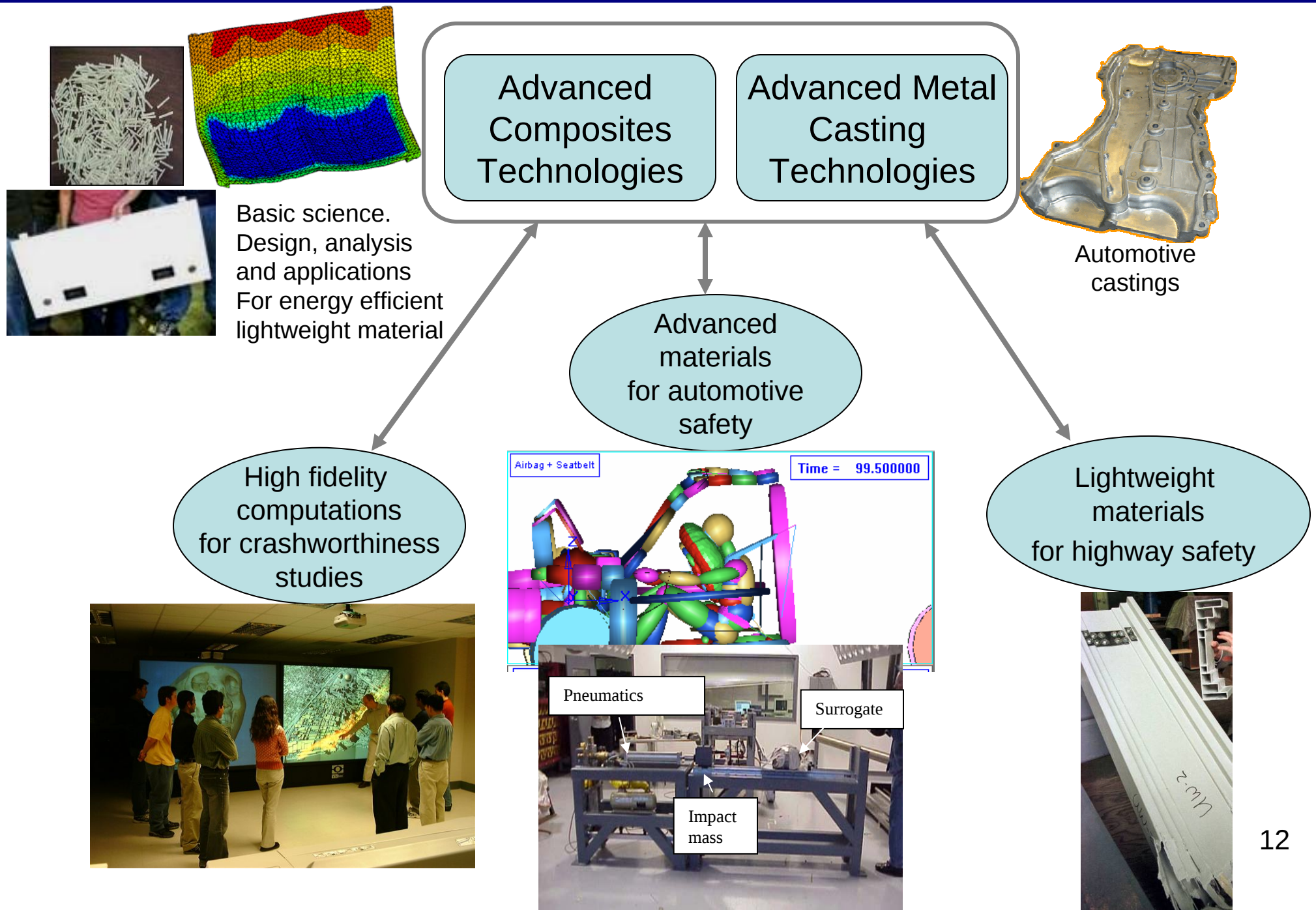
# Accomplishments and Progress: GATE Directly Funded Students (Ahead of target)

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|   | Student Name        | Department and Standing                                         | Thesis / Research                                                             |
|---|---------------------|-----------------------------------------------------------------|-------------------------------------------------------------------------------|
| 1 | Mohammed Shohel     | Civil and Environmental Engineering, PhD<br>(Graduated, Dec 06) | Resin infusion processing of laminated composites                             |
| 2 | Carol Ochoa         | Materials Science & Engineering, PhD                            | Finite element analysis and modeling of thermoplastic composites              |
| 3 | Balaji Venkatachari | Mechanical Engineering, PhD                                     | Simulation of flow fields in automotive bodies                                |
| 4 | Amol Vaidya         | Civil & Environmental Engineering, PhD                          | Sandwich construction for crashworthiness of automotive applications          |
| 5 | Lakshya Deka        | Materials Science & Engineering, PhD                            | LS-DYNA modeling of dynamic behavior of thermoplastic composites              |
| 6 | Satya Vaddi         | Materials Science & Engineering, MS                             | Fire behavior of thermoplastic composites                                     |
| 7 | Felipe Pira         | Materials Science & Engineering, MS                             | Process Modeling of Thermoplastic Composites                                  |
| 8 | Leigh Hudson        | Materials Science & Engineering, MS                             | Pultrusion of thermoplastic composite elements                                |
| 1 | Malina Panda        | Senior, Materials Science & Engineering<br>(Graduated, May 07)  | Development of hot-melt impregnated materials                                 |
| 2 | Daniel Kaliberov    | Junior, Materials Science & Engineering                         | Vibration testing of long fiber thermoplastic composites                      |
| 3 | Michael Magrini     | Senior, Materials Science & Engineering                         | Impact response of long fiber and laminated thermoplastic composite materials |
| 4 | Michael Entz        | Senior, Materials Engineering                                   | Impact analysis of laminated composites                                       |
| 5 | V. Ameya            | Senior, Spain Park High School                                  | Fiber length measurements of LFTs                                             |
| 6 | Hadeel Abdelmajeed  | Senior, Materials Science & Engineering                         | Thermoforming processing of laminated composites                              |
| 7 | Walter Malone       | Sophomore, Materials Science & Engineering                      | Sandwich panel construction for automotive floor boards                       |
| 8 | Victor Long         | Sophomore, Materials Science & Engg.                            | Compression after impact of layered materials                                 |
| 9 | Sueda Baldwin       | Junior, Materials Science & Engg.                               | Long fiber thermoplastic fiber orientation studies                            |

# Technical Accomplishments

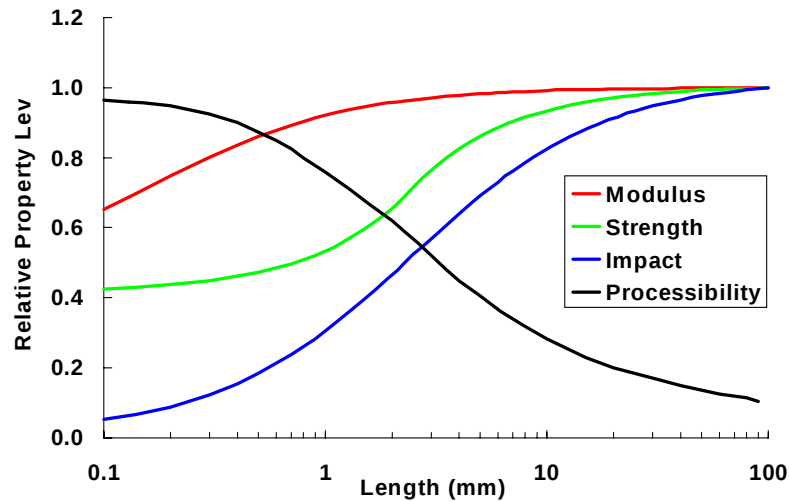
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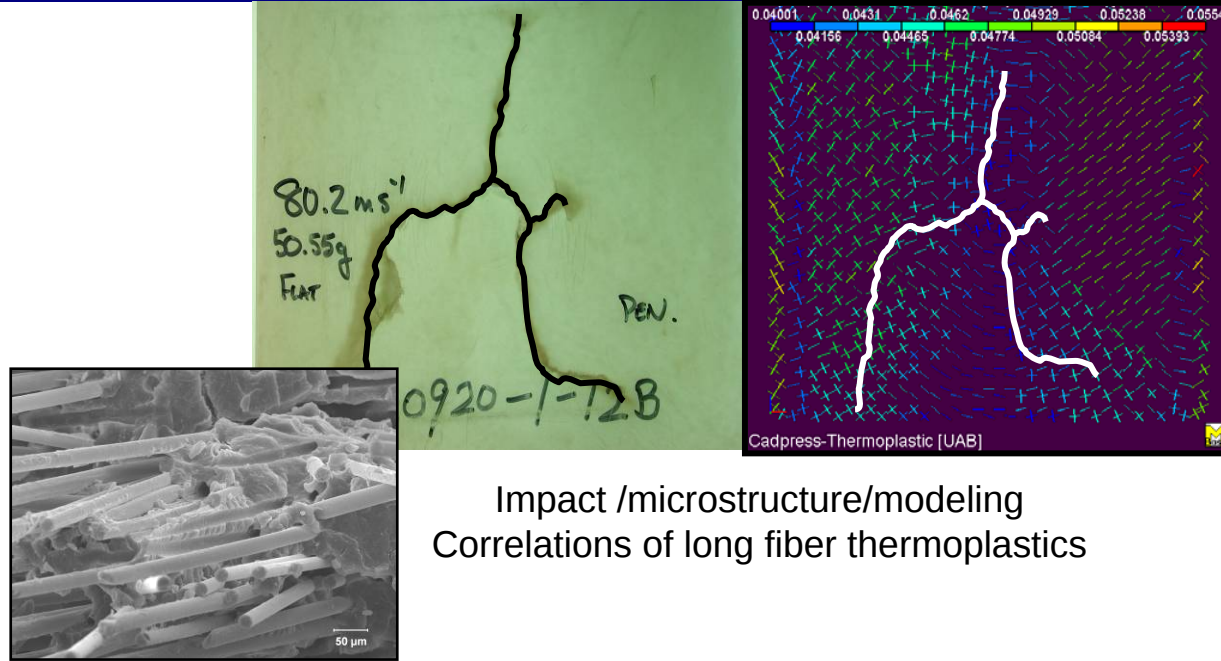
- 40%-60% weight reduction, and ~40% cost-savings featuring energy-efficient thermoplastic composites in DOE relevant mass transit and automotive applications (examples included).
- Strong industry collaboration with GATE research aligned with US industry base and strong DOE relevance.
- Technical publications (see list) by GATE fellows in – fiber/matrix interface studies, multifunctional materials, process and process modeling of castings and composites, impact response, innovation in process methods
- Lost foam casting developed to minimize material porosity
- Advances made in thermoplastic pultrusion and forming applicable to materials for safe highway barriers and energy-efficient automotive structures

# Examples of Basic Research by GATE fellows

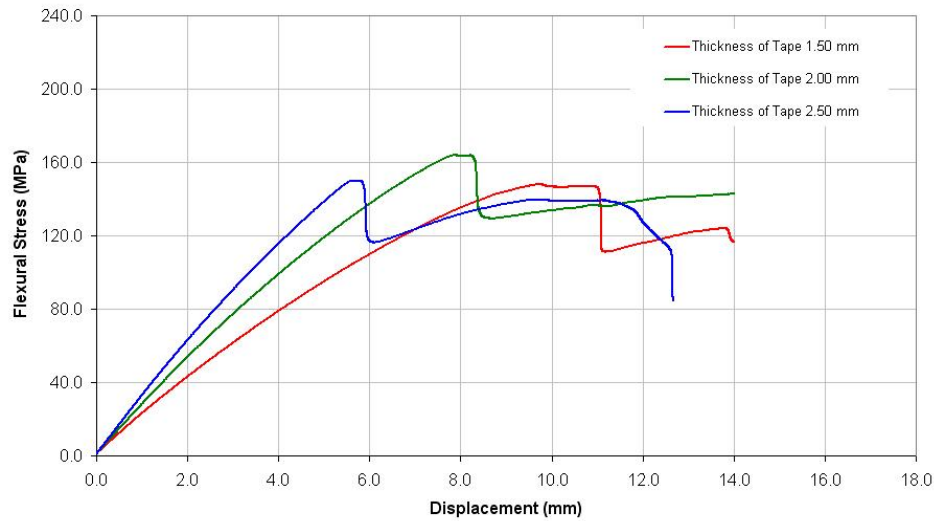
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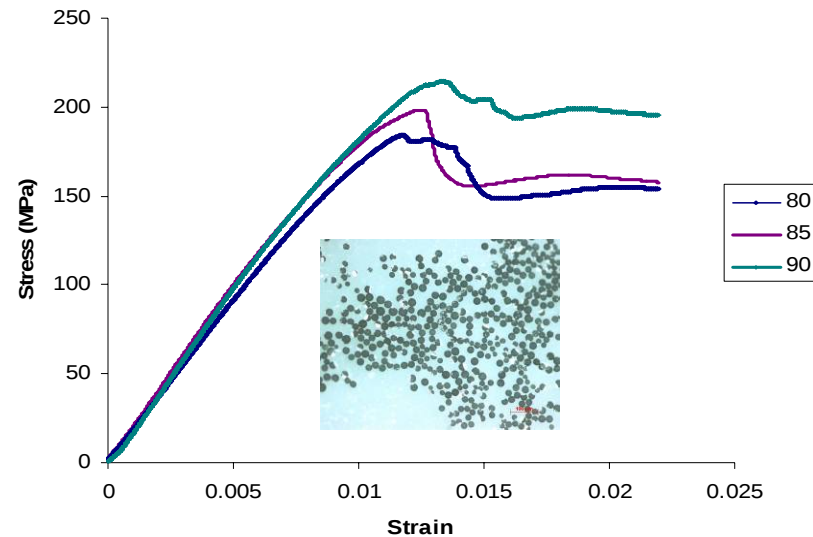
Performance and processability windows for advanced thermoplastics composites



Impact /microstructure/modeling  
Correlations of long fiber thermoplastics



Studies with co-molded continuous tape and long fiber thermoplastics for enhanced energy absorption and crashworthiness, improved safety

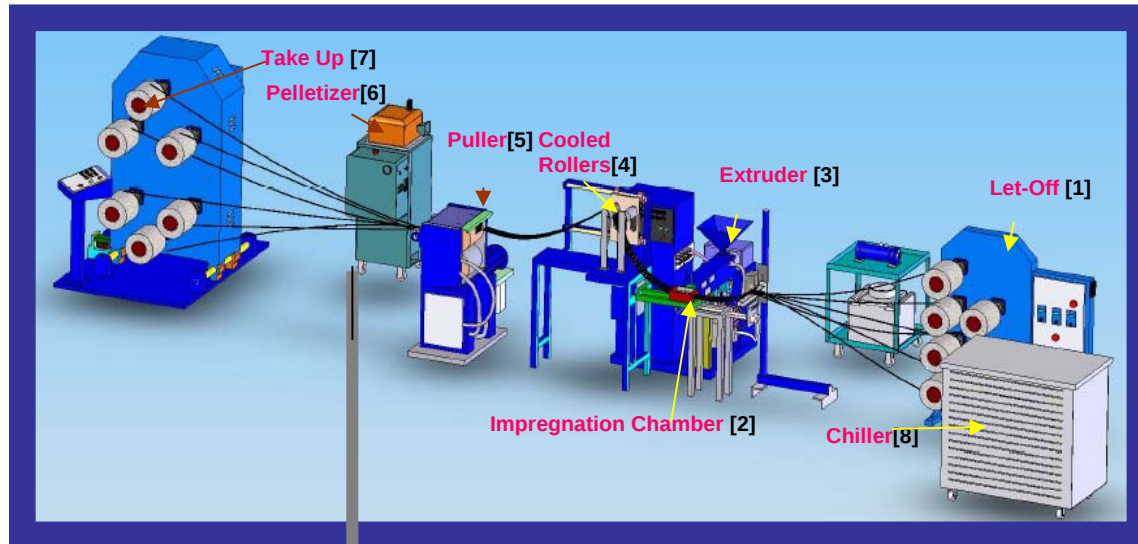


Thermoplastic pultrusion process optimization of materials profiles used in structurally efficient members for transportation

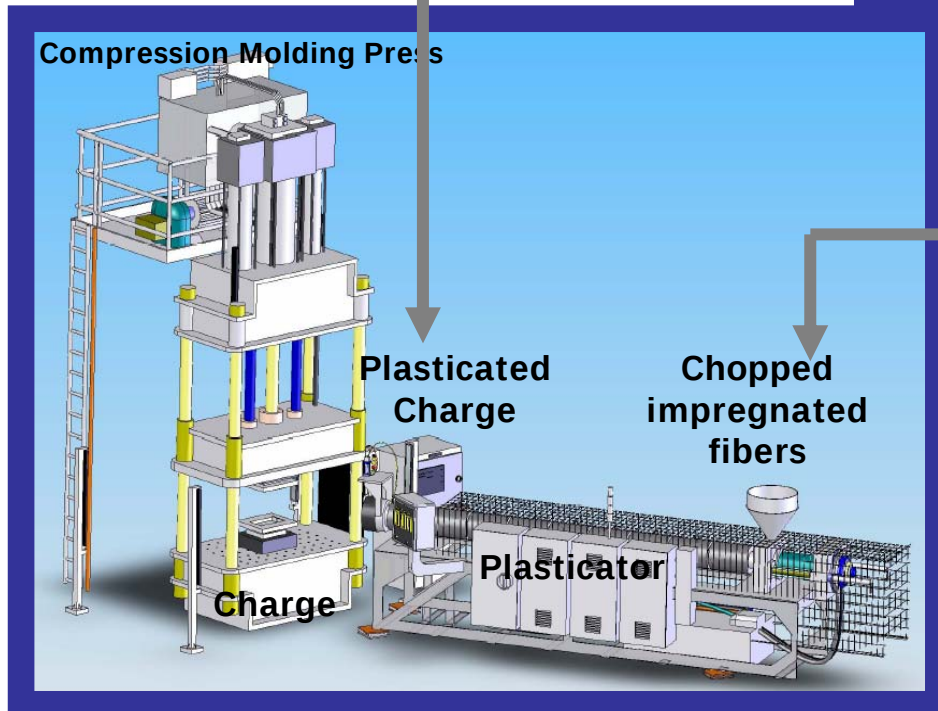
# GATE students are being trained in advanced materials processing and materials selection strategies

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## Charge Extrusion



## Compression Molding Press



LFT Pellets

## Tape & Fabric



# International Recognition of Transportation and Automotive Related Work at UAB

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Engineering & Manufacturing Solutions for Industry

## COMPOSITES TECHNOLOGY

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**REDUCING  
MASS  
IN MASS  
TRANSIT**

**RESIN ADDITIVES  
ADD INNOVATION**

**DUST CONTROL:  
MORE THAN A REGULATORY NECESSITY**

**AFFORDABLE COMPOSITE  
LIGHTWEIGHTS FUEL CELL VEHICLE**

**JEC COMPOSITES SHOW/SAMPE EUROPE  
CONFERENCE PREVIEW**

**NORTH AMERICAN INT'L AUTO SHOW**

COMPOSITES IN: TRANSPORTATION...5, 9, 25, 44, 62  
CORROSION...7 ENERGY... 14 MARINE...15, 59

## inside manufacturing

### THERMOPLASTIC COMPOSITES LIGHTEN TRANSIT BUS

Low-pressure forming processes and low-density, long fiber-reinforced thermoplastic come together to cut weight of aluminum transit bus roof air conditioning door by 40 percent.

Composites material suppliers and molders have spent many years developing and producing lightweight components for automobiles and heavy trucks, aimed at improving fuel efficiency and cost. During this period, much less attention has been devoted to mass transit applications for composites. But that is changing, as transit equipment manufacturers and governments recognize the opportunities to reduce fuel consumption and road wear, particularly for buses.

A key entity in the contracted effort was North American Bus Industries Inc. (NABI, Anniston, Ala.), a major producer of heavy-duty diesel, compressed natural gas (CNG), liquefied natural gas (LNG) and hybrid electrically powered buses. NABI offers standard-floor and low-floor transit buses, including 60-ft/18.2m articulated versions. In 2001, NABI also offered the first bus with an all-composite body (see "Learn More," p. 47).

For this program, NABI provided the platforms from which the UAB/NCC team selected components for its series of demonstrations. In the program's first four years, composite bus seats, floor and frame sections, body panels and a battery box door were produced. For the culminating project, an aluminum door/cover for the roof-mounted air conditioning system was selected for conversion. The net result is an innovative hybrid: an unreinforced thermoplastic outer skin, made using low-cost thermoplastic molding technology, backed with a structural, low-density thermoplastic composite inner panel produced by low-pressure compression molding. The finished product meets or exceeds all requirements for fit, form and function, exhibiting greater stiffness, improved vibration damping and a mass reduction of nearly 40 percent compared to the aluminum production part.



North American Bus Industries (NABI) 60-BRT is a common articulated bus for public transport in major cities. A number of the auxiliary systems, including the air conditioning, are housed on the roof of the bus under access doors similar to that tried in the UAB/NCC project.

Transit authorities in New Jersey, for example, have requested bids for new buses that weigh 5,000 lb/2,270 kg less than current models in use, says Uday Vaidya, director of the Engineering Plastics and Composites Laboratory at the University of Alabama at Birmingham (UAB). Vaidya and his colleagues Sellvam Pillay and Huijun Ning, in collaboration with the National Composite Center (NCC, Kettering, Ohio) and other partners, have recently completed a five-year effort, funded by the U.S. Department of Transportation, to demonstrate how buses can be made lighter using composites.

#### INITIAL TRIAL WITH UNREINFORCED TPO

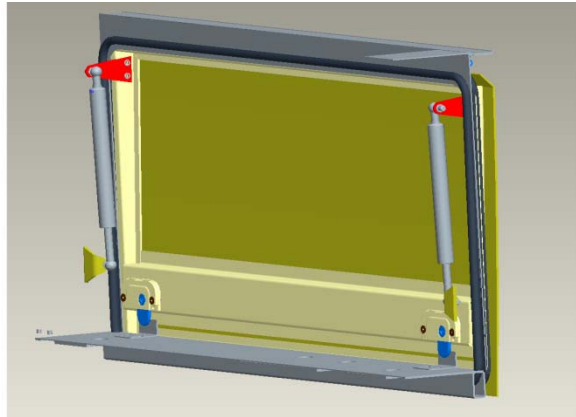
The air conditioning cover doors on the NABI 60-BRT (see "Learn More") are part of a series of rooftop doors that give access to the heating, ventilation and air conditioning (HVAC) equipment. Other doors provide access to natural gas tanks and other systems. The existing production door is approximately 4 ft wide and 6 ft long (1.22m by 1.83m). Weighing 46.2 lb/21 kg, the door

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- UAB featured in front page article on Lightweight Materials Technologies – *Composites Technology Magazine*
- Featured in *JEC Composites* magazine, Europe

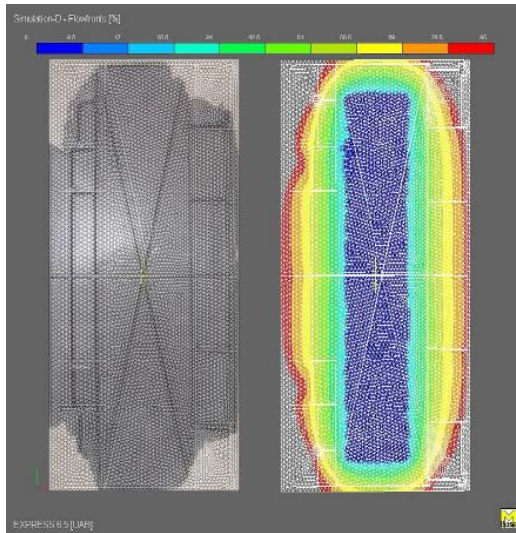
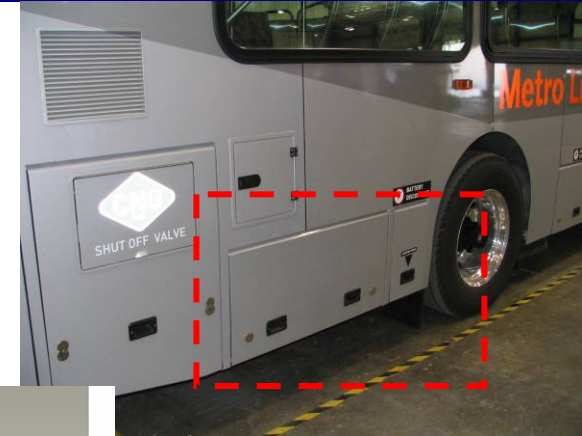
# Thermoplastic Composite Materials for Transportation Applications

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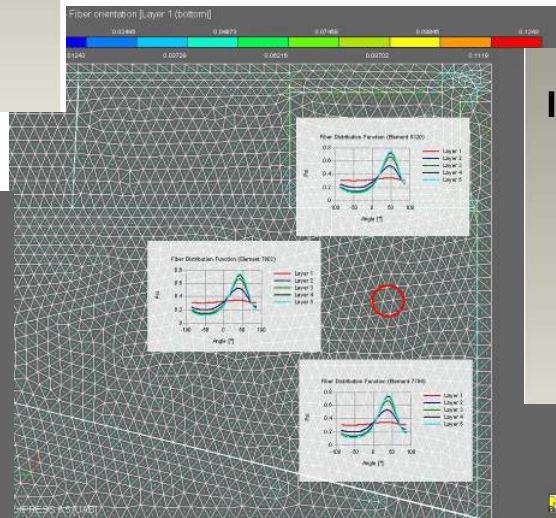


Heavy metal door

60% weight reduction & 40% cost-savings realized by replacement of metal battery door by long fiber composite



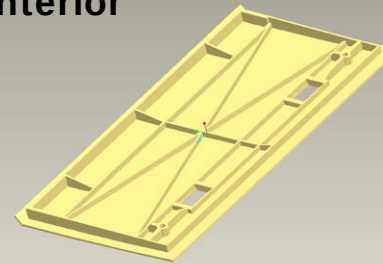
Process flow modeling of long fiber charge



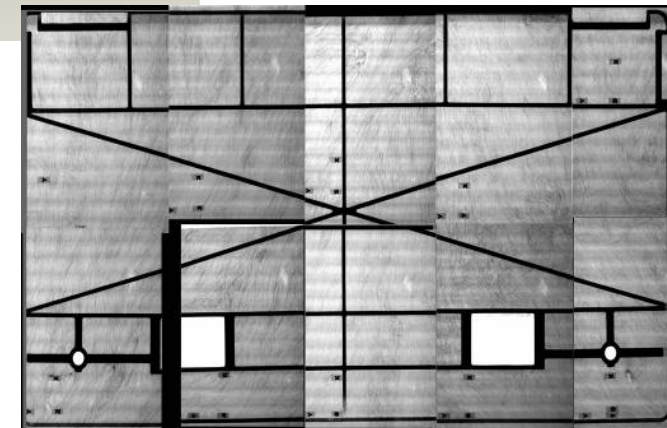
Fiber orientation modeling and prediction

- ☑ IP disclosure filed
- ☑ Technology transfer
- ☑ NABI and other mass transit companies interested in implementation

Interior



Long fiber thermoplastic door; 60% lighter

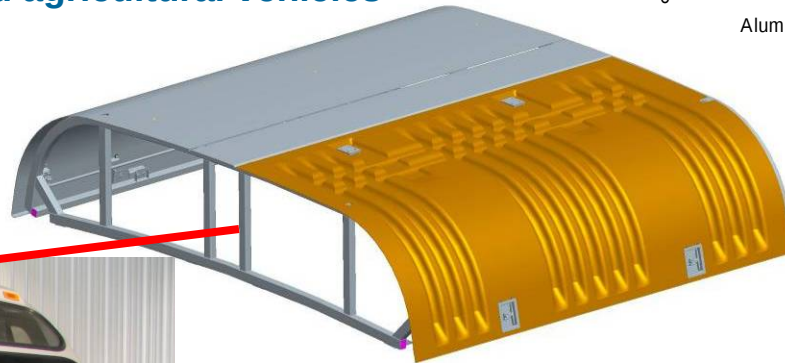
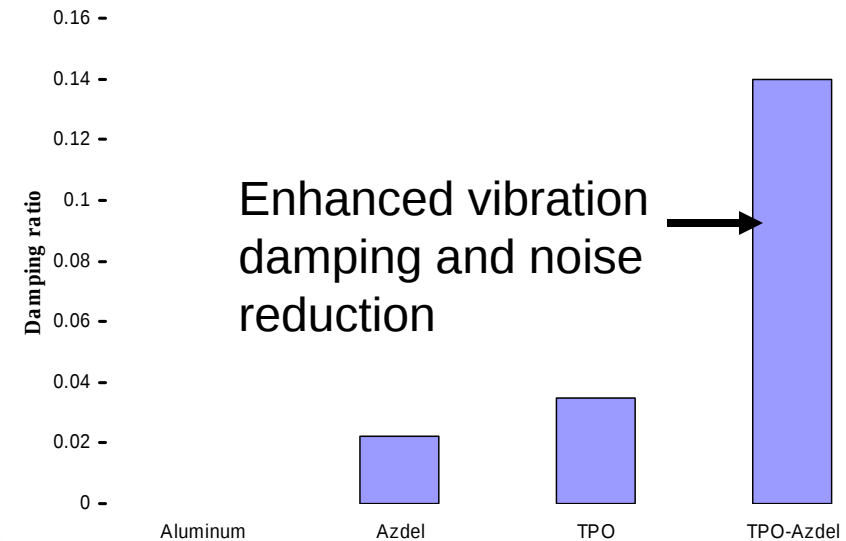


X-Ray studies to evaluate fiber orientation

# 39% lighter Roof Door for Mass Transit Bus; Weight reduction - 450 lbs of roof

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- ❑ Thermoplastic composite technology demonstrated on a large scale part; Innovative utilization of synergistic materials
- ❑ Form-fit function; including existing hardware
- ❑ 39% weight reduction & 77% less free standing deformation
- ❑ Order of magnitude improved vibration damping  
Lowering of Center of Gravity. The BRT bus has ~8 roof doors per segment –potential weight savings 450 lbs
- ❑ Cost effective manufacturing – reduced assembly steps
- ❑ Generic to light rail, trucks and agricultural vehicles



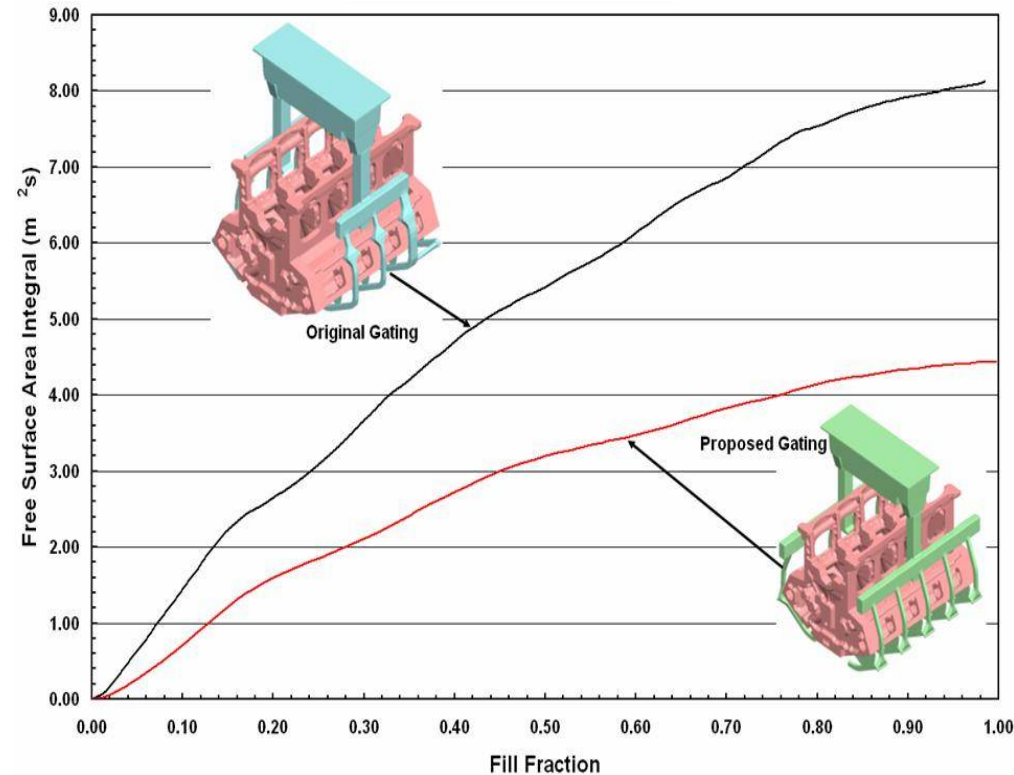
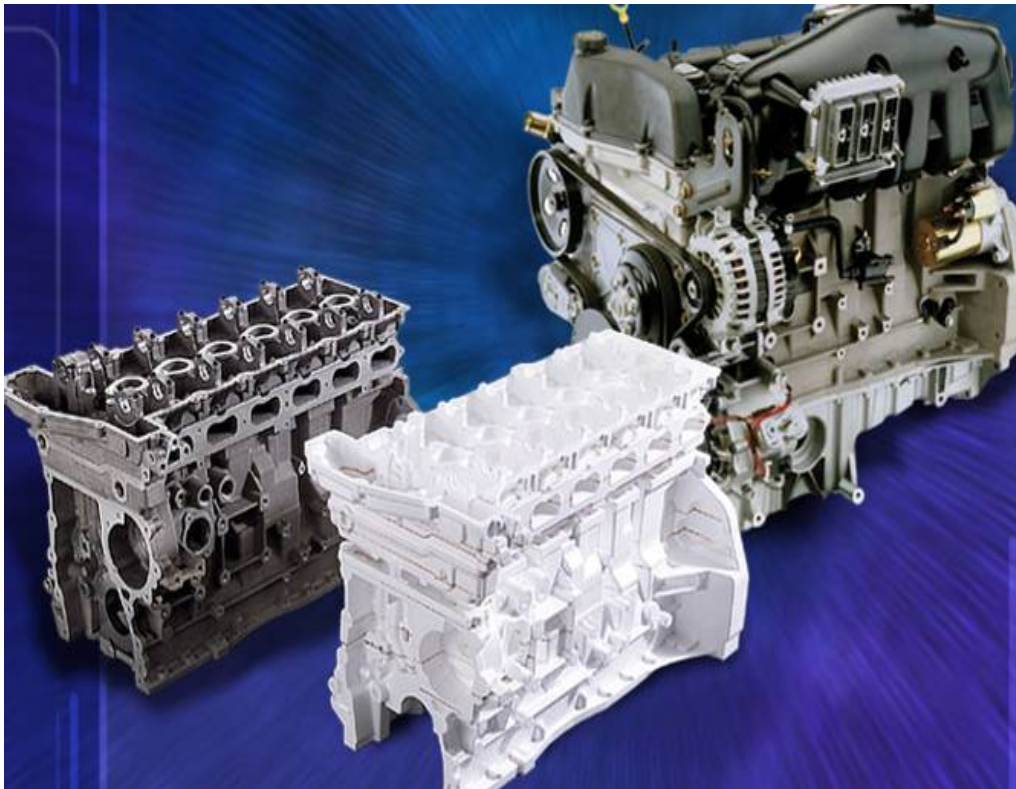
- ☑ IP disclosure filed
- ☑ Technology transfer
- ☑ Awarded best entry at 'SPE Thermoforming Conference', Cincinnati, OH, Sep 2007.
- ☑ NABI and other bus companies interested in implementation



# Aluminum Castings for Automotive Applications

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UAB has an international reputation for expertise in the evaporative pattern (lost foam) metals casting process. Federal funding and industrial partners are supporting research in complex aluminum castings



Modeling of flow during mold filling for engine block castings has led to a 45% reduction in casting defects.

## **GATE COURSES**

- ☑ MSE 635/735: Advanced Composite Mechanics
  - ☑ MSE 634/734: Design and Manufacturing Technologies for Automotive Applications
  - ☑ MSE 667/767: Process Modeling and Simulation for Lightweight Materials
  - ☑ MSE 490/590: Nanomaterials for Automotive Applications
- ME/MSE/CEE: Mechanical Characterization & Performance Evaluation of Advanced  
Lightweight Materials
- BME/MSE/CE: Optimized Lightweight Material Designs for Improved Protection

## **AUTOMOTIVE CERTIFICATE**

Approval is being sought for an “Automotive Certificate” indicating specialization in the automotive area for students who have:

1. Met the requirements for a graduate degree
2. Taken at least 4 GATE courses
3. Completed a research project tied to the automotive or transportation area

# GATE Workshop: Lost Foam Metals Casting

## GATE Faculty: Dr. Robin Griffin & Dr. Alan Drushitz

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# Industry Visits by GATE participants : Visit to Honda of Alabama

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# Accomplishments and Progress: Interaction with Industry Through “Virtual Classrooms”

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Real-time video link to the National Composites Center (NCC) demonstrating the extrusion - compression molding process. Students were able to interact with the participants at the NCC.



- Southeastern Automotive Alliance Consortium – UAB partner with Oak Ridge and National Transportation Research Center (NTRC)
- Student exchange under ORISE and Oak Ridge University User Agreements
- Utilization of high rate testing capability at Oak Ridge for material property evaluation at high strain rates
- Process modeling of composite materials
- GATE advisory board members from Oak Ridge – Dave Warren, ORNL

## Board Members

- Dr. Tom Jackson, UAB School of Engineering Research Director / Chair, GATE advisory board
- Dave Warren, Oak Ridge National Laboratory
- Tom Heyer, Ticona Inc.
- Dr. Lou Ludteke, National Composite Center, OH
- Dr. Bharat Soni, Chair, UAB Mechanical Engineering
- David Powell, Southern Research Institute

## Recommendations

The Board participated in a review of the program (the Merit Review presentation was used) and made the following observations/recommendations:

- New course development in automotive areas should continue at a reasonable pace
- Continue workshops and recruiting events, especially recruiting trips to possible “feeder” institutions
- Increase collaboration with automotive industry in the state of Alabama
- Use Board member’s automotive contacts to advantage

# Summary of GATE activity (Summer 2007-Spring 2008)

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- Targeted Speakers
  - ❖ Dr. John Petrovic, Hydrogen Storage, Los Alamos Laboratory
  - ❖ Dr. Anil Sachdev, General Motors, Lightweight Power Train Materials
  - ❖ Dr. Walt Chaput, Omnisource, Metallurgy in Metal Castings
  - ❖ Dr. Alan Drushitz, UAB, High Temperature Magnesium Alloys
  - ❖ Dr. Paul Swamidass, Tom Walter Business Center, Auburn University, IP and Tech Transfer
- GATE workshops

Workshop offerings in Polymers, Castings, Thermoforming, Microscopy, Extrusion of Plastics, Mechanical Test Methods

  - Included UAB Honors students to participate in GATE workshop / testing activities
  - Visit by GATE participants to Honda of Alabama, Lincoln
  - UAB GATE a member and participant in Alabama Automotive Manufacturer's Association (AAMA)
  - GATE researchers are presenting their work in international/national meetings of DOE relevance – such as SPE Automotive, MS&T, TMS and Lightweighting Materials Conferences
  - GATE student recruiting is aligned with departmental graduate student recruiting efforts (February 26<sup>th</sup> 2008)
  - Strong industry relations leveraging

# Breaking New Ground:

## Structural Composites Applications in Defense, Power Industry, Infrastructure, Transportation and Corrosion-Prevention



**March 4-6, 2008**

University of Alabama at Birmingham (UAB) • Birmingham, Alabama



# Summary of Progress towards GATE Goals and Objectives

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- ✓ Support 3 graduate students/year - *8 graduate students have been supported to date (1.5 years)*
- ✓ Support 4 undergraduates each year – *9 undergraduates have been supported to date*
- ✓ Develop and offer two new automotive related courses per year to impact 20 to 30 students per year – *4 GATE courses have been developed with a total enrollment of 48 students; 2 more GATE courses are being offered in the 2008 year period*
- ✓ Influence at least 30 students per year through hands-on workshops – *to date 150+ students have participated in the five UAB GATE Workshops*
- ✓ Interact with industry through Advisory Board meetings, tours of facilities, collaboration through the virtual classroom, and interaction on research projects (including SBIRs and STTRs) – *all aspects are being addressed consistently and increasing industry collaboration with the UAB GATE*

## IP disclosures filed.....

- Design and Manufacturing of Long Fiber Thermoplastic Composite Access Doors for Mass Transit, Light Rail and Other Transportation Applications (July 2007)
- Design and Manufacturing of Thermoplastic Composite Doors for Mass Transit, Light Rail and Other Transportation Applications (Sep 2007)

# Representative Publications and Presentations (there are over 50)

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1. T. Balaji, U.K.Vaidya, S. Pillay and H. Ning., Design and Development of LFT Battery Access Door., Composites A: Applied Science & Manufacturing (In-print, Dec 2007).
2. T. Balaji, U.K.Vaidya, Processing and Characterization of Co-Molded Continuous Fiber Reinforcement with Long Fiber Thermoplastics, SAMPE Long Beach, May 2008.
3. N. Chawla and K.K. Chawla, "Metal Matrix Composites in Ground Transportation," **J of Minerals, Metals and Materials Society, JOM**, 58 (2006) 67-70
4. Naiyu Sun, Burton Patterson, Jaakko Suni, Eider Simielli, Hasso Weiland, Puja Kadolkar, Craig Blue, and Gregory Thompson, "Heating Rate Effect on Microstructure Evolution during Annealing of Twin Roll Cast AA3105," in Aluminum Wrought Products for Automotive, Packaging, and other Applications, Eds. S. Das, G. Jha, Z. Li, T. Zhai, and J. Liu, TMS, pp. 119-124, 2006
6. U. K.Vaidya., Fire Response of Thermoplastic Composites., Managing Corrosion with Polymers, CD-ROM Proceedings, **NACE International Corrosion 2008**
7. N. Chawla and K.K. Chawla, "Modeling of Particle Reinforced Metal Matrix Composites Using Actual Microstructures," Global Advances in Material and Process Engineering, **SAMPE**, (2006)
8. Derrick Dean, Apollo M. Obore, Sylvester Richmond and Elijah Nyairo, "Multiscale Fiber-Reinforced Nanocomposites: Synthesis, Processing and Properties," **Composites Science and Technology 66** (2006) 2135–2142
9. Haibin Ning, Gregg M. Janowski, Uday K. Vaidya, and George Husman., Thermoplastic sandwich structure design and manufacturing for the body panel of mass transit vehicle, **Composite Structures**
10. P. Scarber, Jr., C.E. Bates, and J. Griffin, "Effects of Mold and Binder Formulations on Gas Evolution When Pouring Aluminum Castings", 2006 **AFS Transactions**
11. S.D Bartus, C.A.Ulven, and U.K.Vaidya., Design and Development of Long Fiber Thermoplastic Bus Seat, **Journal of Thermoplastic Composite Materials**, Vo. 9, No. 2, pp. 131-154, March 2006.
12. U.K.Vaidya and G. Husman., Thermoplastic Composites for Mass Transit Applications., **American Composites Manufacturer's Association (ACMA)**, Birmingham, AL Feb 08-09, 2006

## Companies Funding Research Relevant to the GATE Program

| # | Collaboration                            | Interaction                                 |
|---|------------------------------------------|---------------------------------------------|
| 1 | Triton PMC, AL                           | Automotive Parts Manufacturer               |
| 2 | Britt Engineering, AL                    | Fire Suppression - Automotive Floors        |
| 3 | North American Bus Industries (NABI), AL | Mass Transit - Components                   |
| 4 | National Composite Center, OH            | Prototyping, Virtual Manufacturing          |
| 5 | Shepherd Color Co., OH                   | Functional Inorganic Paints                 |
| 6 | Glasforms, AL                            | Thermoplastic Pultrusion for Transportation |
| 7 | Ticona Inc.                              | Long Fiber & Thermoplastic Materials        |
| 8 | Propex (CURV)                            | PP fibers/PP matrix for Body Panels         |

## Partners for Workshops and Guidance

| # | Collaboration                          | Interaction                                   |
|---|----------------------------------------|-----------------------------------------------|
| 1 | Lawson State Community College, AL     | 2-year college/Student Pipeline / Workshops   |
| 2 | Miles College, AL                      | HBCU/MI college; Student Pipeline / Workshops |
| 3 | Heritage Center, AL                    | Work Force Development / Workshops            |
| 4 | Milwaukee School of Engineering, WI    | Strong Pool of BS Graduates / Workshops       |
| 5 | Calhoun Community College, Decatur, AL | Student Pipeline/ Workshops                   |
| 6 | Oak Ridge National Laboratory, TN      | Guidance & Program Relevance                  |

- Recruit additional quality graduate and undergraduate students into the GATE program (use workshops, personal contacts and financial support to attract students)
- Develop and teach two additional GATE courses
- Expand industry visits to other plants and facilities in the State
- Get Alabama automotive companies more involved with GATE activities, including student internships & expanded faculty/staff interactions
- Obtain university approval for an 'Automotive Certification' for students who have completed 4 GATE course offerings
- Continue workshop offerings in June 2008, Sep 2008 and Dec 2008. One or more of these workshops will be "off site"
- Leverage GATE activities to seek additional co-funding for graduate students with other agencies
- Continue industry interaction and technology transfer