Graduate Education and Research in Lightweight Automotive Materials and Processing

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I. Introduction

In response to government regulations (e.g., CAFÉ for fuel economy), public awareness (e.g., crashworthiness) and intense market share competition, the automotive companies, both individually as well as jointly (e.g., PNGV), are developing technology in many different areas that may substantially change the industry in the next few years. One of these areas is the application of electronics in vehicular control and safety. Many of these electronic applications are already appearing in today's vehicles. Another area, in which relatively quiet metamorphosis is taking place, is in automotive materials. The traditional material for making body and chassis components has been low carbon steel. The need for lighter weight automobiles (to improve fuel economy) has prompted automotive engineers to consider aluminum and magnesium alloys as well as fiber-reinforced polymers for many of these applications. To compete with these lightweight materials, the steel industry is also conducting research on making lightweight steel structures using high strength formable steels, hydroforming, tailored blank welding, etc.

One potential barrier for the use of advanced materials technology for improving fuel efficiency, crashworthiness and performance of future vehicles is the lack of engineers with knowledge and design experience in the application of advanced materials. Many universities offer graduate level courses on materials science. These courses provide fundamental knowledge on the structure, mechanics and physics behind advanced materials. The emphasis on these courses is "science", not "engineering". Students graduating with a materials science degree acquire the knowledge on the fundamentals of materials science and very little on materials engineering. In general, they do not acquire the proper background to design with these materials or to select materials based on their design and processing characteristics. There is a great need for emphasizing interaction between material science, design and processing. Application-oriented courses and research, such as the ones described here, seem to be more appropriate for the automotive industry of the future.

This paper describes first the graduate degree program in automotive systems engineering, followed by the curriculum in automotive materials and how it is integrated in the graduate program on automotive systems engineering. The automotive materials program is part of the Center for Lightweight Automotive Materials and Proceessing, which was established in 1998 with funding from the US Department of Energy under the auspices of the Graduate Automotive Technology Education (GATE) initiative.

II. Automotive Systems Engineering

The University of Michigan-Dearborn started the Master of Science in Engineering (MSE) degree program in Automotive Systems Engineering (ASE) in 1996. It is one of the two interdisciplinary programs that are currently offered in the College of Engineering and Computer Science. Faculty from three engineering departments, namely mechanical engineering, electrical and computer engineering, and industrial and manufacturing engineering, participate in these programs by offering courses, advising students in their capstone projects or thesis and conducting interdisciplinary research. The director of the interdisciplinary programs, who is also a faculty member in the college, is responsible for the administration of these programs.

The development of Automotive Systems Engineering (ASE) program started with the recognition that automobiles are complex systems and engineers involved in designing automobiles should be familiar with the systems approach for solving design and manufacturing problems. The ASE is a 30 credit hour master's program. It includes four core courses, four concentration electives and either a capstone project or a thesis.

Students in the automotive systems engineering program are required to take two core courses that introduce the system level thinking. These courses are "The Automobiles: An Integrated System" and "Automotive Manufacturing Processes". Students are also required to elect two other core courses that are outside of their undergraduate disciplines. Among the elective core courses currently available in the program are:

Automotive Systems Modeling (AE 502)
Digital Systems and Microprocessors (AE 505)
Vehicle Electronics I (AE 510)
Vehicle Ergonomics (AE 545)
Automotive Powertrains I (AE 547)
Material Selection in Automotive Design (AE 581)
Project Management and Concurrent Engineering (AE 583)
Internal Combustion Engines I (AE 596)

In addition to the core courses that provide breadth across disciplines, students are required to elect four concentration courses that provide depth in the area of advanced automotive engineering. The concentration areas in the program are electrical engineering, industrial and manufacturing engineering, mechanical engineering and automotive materials. Students are also allowed to select courses across the concentration area. Many new non-traditional, automotive application oriented courses have been designed in each of these concentration areas. Some examples are given below:

Intelligent Vehicle Systems (ECE 531)
Automotive Sensors and Actuators (ECE 532)
Electric Vehicles (ECE 546)
Robust Design (IMSE 513)
Vehicle Package Engineering (IMSE 593)

Automotive Air Conditioning Systems (ME 537)
Vehicle Dynamics (ME 543)
Design of Automotive Chassis and Body Systems (AE 550)

III. Automotive Materials Curriculum

The automotive materials concentration is the newest concentration in the Automotive Systems Engineering curriculum. Courses offered in the concentration area of automotive materials include the following:

1) Lightweight Automotive Alloys (AE 584) (Table 1)
2) Automotive Composites (ME 587) (Table 2)
3) Ceramics for Automotive Applications (AE 585) (Table 3)
4) Design and Manufacturing with Lightweight Automotive Materials (AE 586) (Table 4)

Topics covered in the above courses are listed in Tables 1-4. Other courses that may be included in this concentration area are Mechanical Behavior of Polymers, Mechanical Behavior of Materials, Materials Consideration in Manufacturing, Injection Molding, Metal Forming, Casting and Composite Materials.

A student specializing in the area of Automotive Materials will typically select AE 581 as one of the elective core courses. This course is intended to provide knowledge on the material selection process in the automotive industry based on product characteristics, manufacturing considerations, cost, environmental issues, customer wants and governmental regulations. The remaining courses developed specifically for the automotive materials concentration emphasize design, processing and recycling issues that are unique for automotive applications. For example, in AE 586, the application of lightweight materials is considered from the point of view of design issues, such as stiffness, fatigue, dent resistance, crush resistance, damping, etc. as well as manufacturing considerations, such as, formability, dimensional tolerance, joining, etc. Recycling considerations in material selection and design are considered through topics, such as design for disassembly, material compatibility and life cycle analysis. Students participate in seminars, group discussions as well as mini-projects that reinforce the concept of systems approach in automotive product development.

The courses on automotive materials have been integrated with the automotive systems engineering curriculum so that students pursuing masters degree in automotive systems engineering can select them for their concentration requirement. The core courses in this program provide a broad perspective of the automotive industry and introduce the concepts of integration of design, manufacturing and product development. The concentration courses provide depth in automotive materials from the perspective of “engineering”, instead of “science”.

In addition to the coursework, students must elect a capstone project or a thesis, which can be on a topic related to automotive materials and structures. The capstone project is usually design oriented and provides an opportunity for student teams (of two) to work on application-oriented interdisciplinary problems. Examples of projects are material substitution and integration using value analysis approach for modular engine air intake system and material alternatives for rear axle housing of a heavy truck. The thesis, on the other hand, is more in-depth on a specific topic of research related to automotive materials. Examples of thesis topics are development of crush resistant aluminum-composite tubes using filament wound over-wraps and press forming of thermoplastic composites for automotive applications. Other research areas in which graduate students are involved include hydroforming of lightweight alloys, low-energy impact resistance of automotive composites, fatigue design methodology for polymers and joining of automotive materials using adhesive, self-piercing rivets and mechanical fasteners.

IV. Conclusions

A graduate education program on lightweight automotive materials has been developed and integrated with an existing master's program on automotive systems engineering. The program offers an opportunity to develop systems level thinking through core courses, concentration courses and capstone project or thesis. In the automotive materials area, the system level thinking entails not only a knowledge on the mechanical properties and structure of lightweight materials, but also the design methodology, processing characteristics and life cycle analysis that are important for their applications in future automobiles.

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Table 1: Topics Covered in Lightweight Automotive Alloys (AE 584)

Aluminum, Magnesium and Titanium Alloys
Structure-Property Relationship in Lightweight Alloys
Physical and Mechanical Properties of Lightweight Alloys
Casting and Joining Considerations
Machining Considerations
Forming and Formability Considerations
Design and Performance Considerations
Recycling Considerations
Metal Matrix Composites
Intermetallics
Automotive Application Case Studies

Table 2: Topics Covered in Automotive Composites (ME 587)

Fibers and Matrix Materials
Mechanics of Continuous Fiber Composites
Mechanics of Random Fiber Composites
Sheet Molding Compounds and Compression Molding
Structural Reaction Injection Molding
Resin Transfer Molding
Thermoplastic Matrix Composites
Processing of Continuous Fiber Composites
Design Considerations
Test Methods
Automotive Application Case Studies

Table 3: Topics Covered in Ceramics for Automotive Applications (AE 585)

Introduction to Structural Ceramics
Physical and Thermal Characteristics
Mechanical Properties
Toughening Mechanisms
Ceramic Matrix Composites
Processing Methods
Designing with Ceramics
Ceramic Coatings
Carbon-Carbon Composites
Thermoelectric Ceramics
Automotive Application Case Studies

Table 4: Topics Covered in Design and Manufacturing with Lightweight Automotive Materials (AE 586)

Review of Design Properties of Materials
Life Cycle Analysis of Automotive Materials
Processing, Joining and Assembly Considerations
Body Panel Applications
Body Structure Applications
Under-the-Hood Applications
Interior Applications
Glazing and Lighting Applications
Engine Applications
Electrical and Electronic Applications