AC 2009-154: A MULTIUNIVERSITY, INTERDISCIPLINARY SENIOR DESIGN PROJECT IN ENGINEERING

Patricia Mellodge, University of Hartford

Patricia Mellodge is an Assistant Professor of Electrical Engineering at the University of Hartford. She received a B.S. in Electrical Engineering from the University of Rhode Island. Her graduate work was completed at Virginia Tech where she received an M.S. in Mathematics and an M.S. and Ph.D. in Electrical Engineering. Research interests include control system design, mathematical modeling of microwave processing, and bio-instrumentation.

Diane Folz, Virginia Tech

Diane Folz is a Senior Research Associate and Laboratory Instructor in the Department of Materials Science and Engineering at Virginia Tech. She also is the faculty advisor for the Material Advantage Student Professional Organization and of the Journal of Undergraduate Materials Research (JUMR). In addition to teaching the materials processing laboratories, she mentors at least one team each year in their senior capstone project.

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Abstract

A senior capstone design project is being conducted jointly by research teams at two universities. The focus of the project is on microwave processing of composite materials, including characterization of materials properties before and after heat treatment and vibrational analysis of the composite system. This year's senior engineering students are participating in the first year of the multi-year project.

To accelerate the project achievements for subsequent student participants, an interdisciplinary transitional summer program is being proposed as a method for technology transfer from this year's seniors to the upcoming seniors via a four-week team interaction.

Introduction

To succeed in today's complex and rapidly advancing global marketplace, graduating engineers must be able to work on interdisciplinary teams that may be geographically spread over large distances. In an effort to expose engineering undergraduates to this kind of experience and develop the necessary skills, Virginia Tech and the University of Hartford are developing a joint senior research project involving two distinct disciplines. The project is related to microwave processing of composite materials, including characterization of materials properties before and after heat treatment and vibrational analysis of the composite system. While neither the interdisciplinary[1,2] nor the multi-university[3] aspects of this project are new concepts, the involvement of an industry partner ensures that this project will last several years. As a result, the universities are also developing a summer program to ensure a smooth transition between groups of seniors.

There are two primary goals for this collaboration, one technical and one pedagogical:

1. To develop a microwave curing process for polymer coatings on instrument woods.
2. To establish a collaborative effort between research programs at Virginia Tech and the University of Hartford.

Project Development

The technical project was initiated in 2005. Based on the expertise of the faculty members in the use of microwave energy for materials processing and their personal interests in guitar building, the concept of replacing conventional heat treatments with microwave techniques was developed. It wasn't until 2007 that they acted on their ideas, visiting four manufacturers over the following year, ranging from small production shops (8 instruments per week) to large-scale manufacturers (>100 instruments per day). One of the manufacturers, Taylor Guitars located in El Cajon, CA, expressed an interest in the microwave technology that could improve their wood curing process and agreed to work with Virginia Tech and the University of Hartford by sharing their knowledge and materials. Because no funding was in place, it was decided to use this project as part of a senior capstone design class. The project developed into one that would be operated jointly between the two universities and would take advantage of the special skills offered by the students, faculty, and departmental facilities of each.

Research Partners

The two universities involved in this research project have very different academic environments and each has its own unique resources that it can contribute to this project. Their general statistics are outlined in Table I. Virginia Tech is a large public institution that places a large emphasis on its research program, exceeding $350 million in grants annually. As a result, the university has in place many of the resources needed to engage in a wide variety of scholarship. These resources include access to state-of-the-art facilities, faculty expertise, and graduate student assistance.

The microwave processing facility at Virginia Tech is unique in that it contains a wide variety of specialty research model microwave ovens operating at various frequencies and variable power. The most valuable component of the microwave facility is the expertise of the faculty and students. They have gained a reputation internationally for their research in this area and for their contributions to the body of knowledge on this topic.

In addition to the processing lab, the researchers at Virginia Tech have access to a world-class characterization and testing center. This facility allows for complete profiling of the processing-structure-property relationship which is vital to understanding and controlling materials performance. The undergraduate students are being trained to use the instruments applicable to this project.

By contrast, the University of Hartford is a much smaller private university that focuses on undergraduate education. This emphasis can be seen in the relatively high percentage of undergraduate students enrolled in engineering. Class sizes are below 30 in all engineering classes, while 15-20 is a typical size. While the student/faculty ratio is similar at both schools, all faculty at the University of Hartford teach. Faculty are expected to engage in scholarly activity, but it is focused around projects that involve undergraduate students.

The University of Hartford houses an acoustics laboratory that features a 100 Hz reverberation room and a 100 Hz anechoic chamber, as well as a host of analytical equipment for monitoring, recording and analyzing vibration. Students work on real-life acoustics application projects coordinated with sponsors from across the USA. In this project, the undergraduates will work with faculty to evaluate the effects of various coatings on a specific species of wood.

Taylor Guitars is a manufacturer of high quality acoustic and electric guitars widely recognized for their use of state-of-the-art technology in instrument design and manufacturing. In particular, Taylor has pioneered the use of ultraviolet (UV) finishes to provide better protection of the wood while exceeding environmental emission standards. Together with the university partners, they have established a protocol for preparing samples of various woods in geometries suitable for the initial processing investigation as well as for the core feasibility study on larger components.

The wood samples, coating materials, and extensive expertise regarding guitar manufacturing all were and continue to be provided to the university researchers at no cost.

Table I: *Comparison of the two universities participating in the research project.*

	Virginia Tech	University of Hartford
Type	Public	Private Not-for-Profit
Total Enrollment	28,259	7,366
Undergraduate Enrollment	23,533	5,695
Engineering Undergraduate Enrollment	5,922	324
Engineering Graduate Enrollment	1,549	33
Student/Faculty Ratio	16:1	14:1
Carnegie Foundation Classification	RU/VH	DRU
Campus Size	2,600 acres	350 acres
Setting	Primarily Residential	Highly Residential
Location	Mid-Atlantic	New England

Technical Background and Goals

It had been demonstrated through extensive research over the past two decades that microwave heat treatments could lead to reduced processing times[4], lower processing temperatures[5,6], reduced hazardous emissions[7] and selective response of many materials to electromagnetic energy[8]. Although all of these characteristics eventually may lead to improvements in the manufacturing process, it is the selective response that is of primary interest in at the beginning of this investigation.

Unlike most, if not all, other guitar manufacturers, Taylor Guitars uses a UV curing process to heat treat the coatings on their instruments. This process and the special UV-activated polymer coating material were designed specifically by Taylor engineers and their materials suppliers. The process was considered a breakthrough in manufacturing guitar finishes as it allowed for rapid curing (as little as 30 seconds). The method used prior to this innovation required air dying time between the coats (5 to 10 coats). Taylor's UV curing chamber is illustrated in Figure 1.

In addition to the process improvements, emissions from the curing process were reduced significantly due to the water-based coating composition. This point proved to be a significant improvement over the previous organic-based materials, especially given that California air emission standards are restrictive[9].

Manufacturers of instruments are aware of the fact that the polymer coatings continue to cure (cross-link) for several weeks following manufacture. In order to more tightly control their products and to make further innovations to their process, Taylor engineers expressed a goal of completely curing the coatings prior to shipment. It was with this goal in mind that the university project was developed.

Figure 1: Ultraviolet curing chamber at Taylor Guitars, El Cajon, CA[9].

The potential to use microwave energy to penetrate deeper into the coating and drive cross-linking of the polymer is the overriding goal of the processing research. However, accomplishing this goal is not sufficient if the process is to be considered as a serious candidate for scale-up. The tonal qualities of the instrument must be maintained. Therefore, the University of Hartford students are focusing on the vibrational testing of the microwave-cured wood samples produced at Virginia Tech.

The project was designed in stages, with processing initiated in August 2008 and the vibrational testing initiated in January 2009. The basic project flow chart is provided in Figure 2.

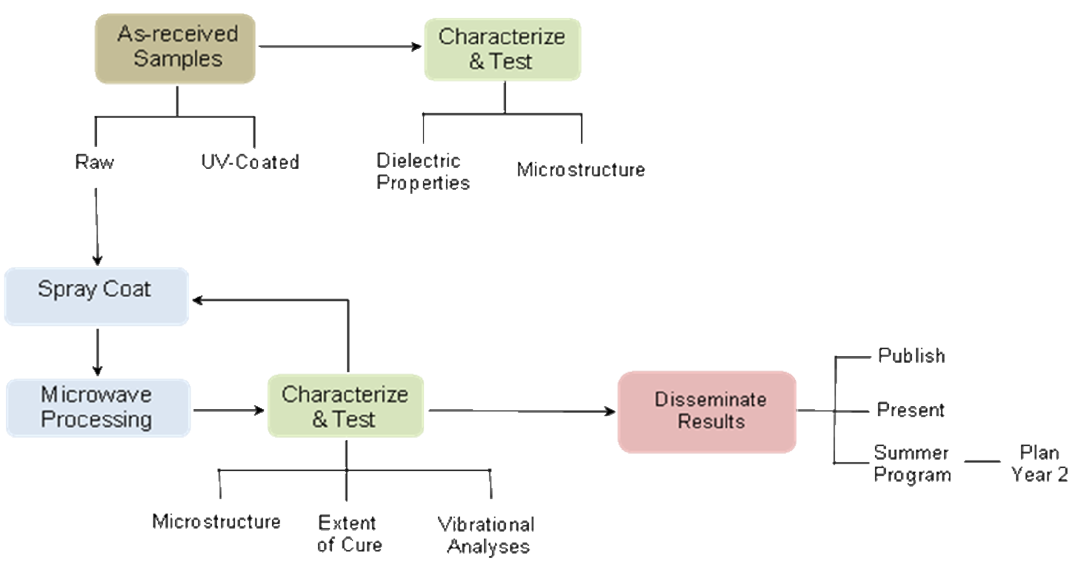

Figure 2: Project flow chart for microwave processing of instrument wood.

Progress to Date

Student and Faculty Collaboration

Each of the lead faculty members associated with this project has made multiple visits to the partner university for the purposes of planning and experimental activities. Also, in the fall of 2008, two student members of the processing team accompanied their faculty advisor to the University of Hartford to present the project overview to potential student collaborators and to tour the acoustics laboratory. The purpose of this activity was to recruit their counterparts, the seniors who would perform the vibrational testing on the microwave-processed wood samples. This experience was unique for students from both universities. Each group had the opportunity to meet the faculty and students from the other's institution and to learn about research conducted in a completely different engineering discipline.

One major goal of the collaboration is for the students to produce a collaborative paper for submission to an undergraduate research journal. The experience of publishing together is extremely valuable and one that prepares them for future co-authorship in their post-academic careers. Additionally, the students from each university will be encouraged to submit their work to a technical conference. The fact that they have met and discussed the project in person will help them in this effort as they will not be working from a distance with complete strangers. A second meeting is planned for the spring semester during which the students can discuss technical progress to be reported in the paper.

Experimental Work

Both the technical and collaborative aspects of the project have been progressing since the seniors first began their work in August 2008. Taylor shipped 6 in. x 6 in. x 0.11 in. samples of two different woods, maple and Indian rosewood, commonly used in production of guitar back and sides. Half of the pieces were shipped "as dried" (moisture content in the range of 4 to 6%) and half were coated and UV cured at the plant prior to shipment.

The processing team has progressed in the areas of materials characterization, equipment design and construction, and process development.

Characterization

Dielectric properties of the uncoated wood samples were measured using a cavity perturbation method. This technique provides an indication of the potential for microwave absorption at a specific frequency (in this case, 2.45 GHz; the frequency used in processing experiments). Based on the dielectric loss (calculated based on the measured dielectric constant), it was determined that both the wood species were good candidates for microwave heating. The maple exhibited slightly more consistent values, which is not unexpected since it has a more consistent structure (rosewood has more structural features). For this reason, the maple was selected for coating experiments to produce samples for vibrational tests.

Optical microscopy was used to evaluate the structure of the uncoated and coated wood samples. Particular attention was paid to the cross-sectional features to determine the depth of penetration of the coating into the wood. These analyses would be repeated on the microwave-coated samples and the results of the UV- and microwave-cured would be compared.

Equipment Design

In order to perform vibrational analyses, the size of the wood samples was increased. The new maple samples were cut to 5 in. wide and ranged in length from 23 in. to 27 in. (planks). The thickness remained the same as the original samples. This change in geometry demanded a change in the processing system. Original processing tests were performed on samples approximately 1 in. x 2 in. They were processed in a single mode microwave cavity in which the distribution and intensity of the electromagnetic field was known and controllable. However, this processing scenario allowed for only very small samples. In order to scale up to the planks, a multimode microwave system in which a broadly distributed microwave field could be achieved. Modifications were made to the system to allow for mode stirring, a technique that increased the uniformity of the field. In order to achieve a constant exposure time in the cavity, a conveyer system was designed to pull the plank through the microwave field at a uniform, controlled rate (Figure 3). Not shown in the figure are the motor system to pull the planks through the microwave field and the spray coater to deposit the coating.

Figure 3: Modified home-model microwave for multimode microwave curing of wood planks.

Process Development

Several methods for depositing water-based urethanes on the wood were tested. It was determined that spraying offered the most uniform technique for depositing a uniform coating on the wood substrates. A high-quality sprayer was used to coat the samples prior to passing them through the microwave cavity. A balance was struck between the rate of coating deposition and of passing the coated samples through the field. The samples were relatively cool upon leaving the microwave cavity and could be handled almost immediately.

Summer Transfer Program –"Students Teaching Students"

Since the overall goal of the project is to develop a microwave process for Taylor's production line, it is expected that the research will continue for a number of years and involve several teams of seniors. For the sake of progress, it is important that each year's seniors build on the previous work. However, it is the nature of senior capstone design projects to lose momentum when one team of seniors graduate and incoming seniors start the project. This phenomenon may be exaggerated by the collaborative aspects of this particular project. While the relationship between the faculty members is well-established, the incoming student teams will have a learning curve to complete prior to making significant contributions to the project. Therefore, a transitional program is being developed to minimize repeated steps normally required for the students to learn the process. As this is the first year the two universities have worked together, the summer program is being implemented as an integral part of this collaborative activity from its inception. It is not a corrective measure for a problem between the partners, but a fundamental component of the collaboration design.

There are two main goals for the summer transfer program:

1. Technology/knowledge transfer: Incoming students will learn the project history, status, and potential directions for future work
2. Closing the gap: Students will travel to each university to learn the techniques from a different discipline.

The summer program can be structured into three phases as shown in Figure 4. Each phase can be implemented independently based on available funding. In Phase 1, incoming seniors from both schools travel to the Virginia Tech to work with outgoing seniors. The outgoing seniors, in conjunction with faculty, will reproduce their processing and characterization to train the incoming students so that they understand the how to create and test samples. These samples will then be taken to the University of Hartford which will host the incoming seniors for a similar training session on how to perform vibrational testing. At the end of this phase, the students should understand what work has been completed by the previous year's seniors and how the work done at each school fits into the overall project.

In Phase two, all students and faculty will travel to Taylor Guitars to meet with manufacturing supervisors, research engineers, and company management to present results of the first year of work. They will also tour the facilities to become familiar with the industrial processes, the technical issues of manufacturing, and to put the project work into broader context. The incoming team will have the opportunity to discuss their path forward to be sure the work is in line with the needs of the company. Benchmarks for success can be discussed and established and go/no go points determined.

The third phase involves disseminating the results. Students will travel to present their technical work in conferences such as the Material Science and Technology Annual Conference, Annual Conference on Composite Materials and Structures, or other appropriate conferences sponsored by the IEEE or Acoustical Society of America. Faculty will travel to present their project experiences at meetings such as the ASEE Annual Conference and the National Educators

Workshop. Furthermore, while not explicitly part of the summer program, it is expected that outgoing teams from each university will jointly write their results and submit to a technical journal for undergraduate research.

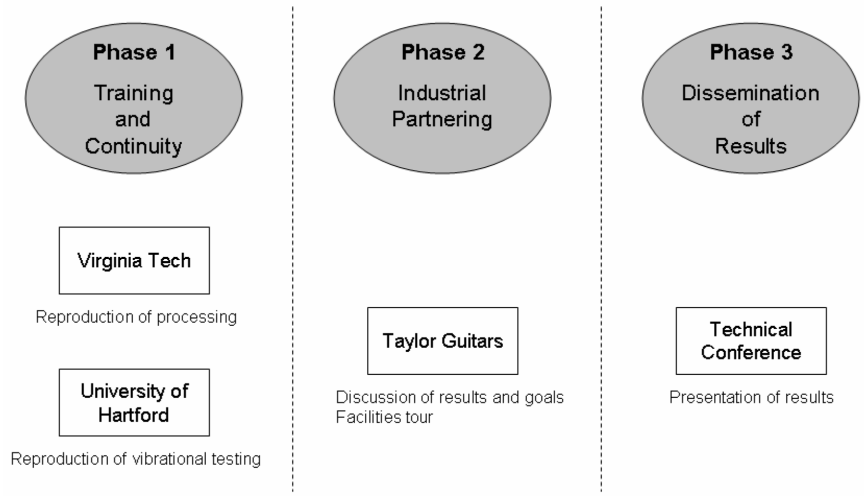

Figure 4: The three phases of the summer transfer program.

The design of the program is such that the experienced learners (the outgoing seniors) become the mentors for the inexperienced learners (the incoming seniors). Kolb and Fry's experiential learning cycle[10] can be applied to the experience of the capstone students as they progress through the program; however, it is important to realize that the process is not necessarily a linear sequence.

Students at Virginia Tech are recruited into the program in the spring semester of their junior year. As the experimental components of the capstone course are initiated in the following fall semester, the students spend a portion of the spring and summer in the "active experimentation" portion of the cycle. They plan out the activities they will conduct the following fall and they are engaged in applying the knowledge gained through coursework. They progress through the "concrete experience" as they are involved in the core of the research activities. "Reflective observation" is a continual process throughout the two-semester capstone experience as the students revisit various aspects of the work and revise research activities to incorporate the most recent empirical findings. This process of revision becomes even more crucial as the University of Hartford research team enters the project in the spring semester of their senior year. Since the capstone project activities for the two collaborating teams are offset by a semester, new data generated by the team conducting the most critical aspects of testing will have a profound effect on the decision-making process of the Virginia Tech students. They will be involved simultaneously in the "reflective observation" and "abstract conceptualization" phases of the learning cycle as they incorporate new information, expand their understanding of the empirical data and collaborate to generate a summary technical paper.

The summer program will bring a new aspect to the capstone experience. The students now will push their knowledge beyond the final paper and/or presentation normally required for undergraduate researchers. The process of synthesizing their experiences, both experimentally and as they progressed through the project design phases, will push them into the category of "experts," at least from the perspective of the incoming undergraduate research teams.

Assessment Plans

Initial plans are to assess the success of the collaboration. Some of the metrics proposed are enumerated below.

- *Students*: How many students are involved at each university per year?
- *Process applications*: Are new applications (other than guitar wood coatings) being developed as undergraduate projects?
- *Funding*: Are the faculty able to bring in sufficient funds to maintain the senior research and the summer program? What is the rate of acceptance verses the number of grant applications submitted?
- *Publications*: How many journal articles and/or conference papers are submitted and how many are accepted?
- *Patent disclosures*: How many patent disclosures have been filed? Have any been granted?
- *Scale-up*: Is there industrial intent for prototype development within a reasonable timeframe (~5 years)? Have any technology license agreements been established?

Over the coming months, plans will be made to assess the impact of the summer program on the success of the collaboration and on the academic progress of the students involved.

Faculty Collaboration

Throughout the technical and summer programs, the faculty members will play a vital role, that of mentors. They will provide technical guidance, but also will provide the continuity that will build a successful research team and academic collaboration over a multi-year program.

While the technical program will be able to continue with minimal funding for supplies and characterization, the summer program will require significant funding. The faculty advisors will continue to seek the funds necessary to ensure this vital part of the program. It is this aspect of the collaboration that is unique and which stands to provide the most benefit the students and the project.

Conclusion

The first year of the project is concluding in June 2009 with the implementation of the first summer program. This year's seniors will conclude their research projects in May 2009 and will submit a draft to an appropriate journal for review. They will be encouraged to collaborate on an abstract for a professional conference which either they or the new seniors can present in the summer or fall of 2009. The summer program team will hold discussions with Taylor engineers to lay out the next phase of the research project to be initiated in August 2009 with the new round of processing work. Modifications to the characterization and testing performed at both universities will be made based on results from the first year's research.

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