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Advancing Composites Education and Training through Curriculum Design

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Abstract

This paper will outline the increasing occurrence of polymer composite material applications within industry and the challenges facing post-secondary educational institutions to adequately prepare engineers and engineering technologists/technicians. It will also address the many facets of composites and how to develop coursework to meet both the fundamental concepts of composites along with addressing specific hands-on fabrication practices and applications.

Composite material usage is experiencing continuous growth in a variety of application areas including automotive, aviation, recreation, and building products. Both design engineers and consumers are seeing the many benefits provided by the unique characteristics of this modern day family of materials. Composites are an excellent example of how different types of materials can work in synergy. The aircraft industry is going through a metamorphosis regarding the use of composite materials, as evidenced by Boeing's recent announcement on its totally new designed composite 787 (Dreamliner) aircraft. As a result, many aircraft companies are seeking to re-tool their workforce. It is a paradigm shift for their employees who have years of experience working with metals and now must begin working with composites. In this industry, one course does not fit all, because of such varying degrees of the knowledge base along with the specific application requirements put forth by the industry users. Working with such dynamic materials and processes in conjunction with meeting the needs of designers and manufacturers will continue to challenge educational institutions in the future.

Introduction

The vast world of composites has grown rapidly and significantly since its first large scale applications within the military sector during WWII and the late 1940's and early 1950's. The unique combination of performance benefits offered by composite materials has now propelled its use into almost every industry sector within today's global economy. Composites or more specifically, Fiber Reinforced Polymers (FRP), consist of a polymer matrix, usually a thermoset plastic and a variety of reinforcements, including glass, carbon (graphite) and aramid (Kevlar) fibers. It is this unique combination of complementary properties that, when combined, create an entirely new material with very specific characteristics. This makes the design and use of composites more desirable than some of the more traditional materials in many different applications. To show the impact on society that composites has had, the growth rate in the composites industry in 2004 was 8.7 %, as compared to the global economic growth rate of just 4% in 2004. An increasing number of designers and engineers are realizing the potentials and possibilities of composites based upon these inherent synergistic properties:

- High Strength
- Light Weight
- Design Flexibility
- Dimensional Stability
- High Dielectric Strength
- Corrosion Resistance
- Parts Consolidation
- Finishing
- Standard Shapes

In fact, in the last 45 years, there have been more than fifty-thousand successful composite applications, and the outlook for the composites industry appears to remain healthy over the long term. Composites are currently serving these key market sectors:

- Aerospace
- Automotive
- Marine
- Construction
- Oil and Gas
- Wind Energy
- Sports and Recreation

One very large, specific application at the forefront of composites design capacity is the new Boeing 787 Dreamliner. Boeing originally referred to this 250 passenger jet aircraft as the 7E7, with the “E” referring to “efficient”. Its extensive use of structural composites (about 50%) would offer prospective airlines a minimum of 20% greater fuel economy than today’s in-service aircraft. Composites would yield better fatigue and corrosion resistance, higher strength-to-weight ratios, provide a more integrated structure and increase the useful life and residual value of each aircraft. Boeing is so convinced of reduced maintenance requirements due to the composites structure that they are issuing long term maintenance agreements with the aircraft, a practice normally unheard of in the industry. Boeing also believes that due to composite materials’ resistance to condensation, it would allow engineers to increase cabin humidity to enhance passenger comfort. The 787 will also enjoy a 30,000 to 40,000 pound reduction in weight compared to its closest counterpart, the Airbus A330-200. Composites continue to replace aluminum as the material of choice, and as a result, aluminum comprises only 12% of the 787 airframe structure. In the future, Boeing estimates a 19:1 part count reduction where composites will replace aluminum.

It is evident that the use of composite materials and applications will continue to grow, not only by replacing current materials in previous applications, but more importantly by designing new composite applications, unique in form, structure and characteristics. Through composites, engineers and designers can truly be creative industrial artists.

The challenge for the educational system is to provide learning and training opportunities to help grow the composites knowledge base in its many forms. Composites as both a material and application must be more widely introduced to all mechanical/manufacturing engineering and engineering technology students. It should not be buried inside an undergraduate course with just a brief overview nor should it be strictly treated as a precious commodity reserved only for graduate research labs. Treatment of traditional engineering materials continues to dominate most applications within engineering related coursework. Composites education deserves a significant role at both the university level as well as appropriate post - secondary technical education disciplines. All engineering and engineering technology students will benefit by an increased and more intense exposure to composites. Composites education should be categorized into three distinct yet connected areas:

- Materials
- Manufacturing Methods
- Design

From a curriculum design standpoint, it should be taught at all levels of instruction with the three individual components bundled together in order to form the complete picture of composites technology. More emphasis can be placed on certain areas depending upon instructional program outcomes as predicated by any regional specific composites industry, such as aviation, marine or automotive.

In an engineering educational pedagogy, there are two distinct tracks that composites education can proceed. The first track involves a complete stand alone program in composite materials at either an Associate's degree level within an engineering technology discipline or at a baccalaureate level within engineering or engineering technology. The second path would be to develop more comprehensive coverage of composite materials within an existing materials course or develop a new single course that would be mainstreamed and required for all graduates. These two approaches would better integrate the material, rather than having it fragmented. This would also lend itself to a more concurrent engineering approach, thereby insuring that graduates are more qualified to work in the composites industry.

Composites Material Engineering at the Baccalaureate Degree Level

A case for the stand alone composites material engineering program was made by Winona State University (WSU) in Winona, Minnesota, in 1989. Today, the Composites Materials Engineering (CME) program at WSU is the only undergraduate engineering program totally devoted to the study of composite materials. From nationwide surveys, it was clear that the traditional engineering programs were not meeting the growing needs of the composites industry. The industry needed engineering graduates that understood composites from both a material science perspective, as well as from a manufacturing and applications orientation. WSU responded with a program that accomplished the industry criteria as well as developing research applications for composites.

The objectives of the CME program are to develop graduates:

- With theoretical knowledge and hands on ability to design composite materials systems, components, and processes in a cost effective manner
- Design, conduct experiments and analyze data relating to structure, properties, processing, and performance of materials
- Use engineering tools to select, analyze, design, fabricate, and test composite materials

The CME curriculum consists of 128 semester credit hours divided into four major core component areas, along with elective courses and University Studies requirements. The four major core areas are:

Material Science and Engineering
Engineering Mechanics
Chemical Engineering
Manufacturing Engineering

There are two options within the CME program: the Chemical Option and the Mechanical Option. The Chemical Option focuses on the development, processing, and chemistry of the materials used in composites including fibers, matrices, and fiber/matrix interface systems. The educational objectives of the Chemical Option would include:

1. Study chemistry and structure of constituent materials
2. Perform material analysis to achieve desired properties
3. Concurrently design and manufacture engineered materials
4. Determine performance of materials for given application

The Mechanical Option is more involved with the design, analysis, and manufacture of composite structures. Its major educational objectives are:

1. Select materials based upon constituent materials
2. Perform mechanics and/or structural analysis
3. Concurrently design and manufacture engineered components or structures
4. Determine performance of materials and structures

Within the overall course inventory of the CME program the following specific composite related courses include:

- Introduction to Composite Materials
- Topics in Composite Materials Engineering
- Composites Manufacturing
- Topics in Composite Materials Engineering
- Polymer Processing
- Mechanics of Composites
- Mechanical Characterization Laboratory
- Composite Characterization Techniques

- Design Project I/II

The laboratory component is an integral part of the CME program. Hands-on experiences are emphasized throughout the curriculum in various laboratory and lecture-lab courses. Students gain experiences in experimental methods in a number of laboratory courses as well. Because of the hands on experiences and involvement with industry, the CME program has been involved with a number of regional and national engineering competitions. These include composite bridge building and solar car race competitions.

The major contribution that this undergraduate CME program has had is to the composites industry by providing them human resources to expand and develop their marketplace objectives. This is evidenced by a high percentage of graduates that have gone directly into the field upon graduation, with the remaining students choosing to continue their education within the field at a graduate level to enhance their research and development capabilities.

Industry continues to have a need for undergraduate engineering education at a baccalaureate level in composite materials as advancements are made in both materials and processing methods. The WSU-CME program is a direct response to those needs and continues to be at the forefront of composites education. The curriculum continues to remain current because of industries involvement with assessments and advisement from professional practitioners and experts in the field. The niche remains for this level of composites engineering education and will only increase with continued developments from industry as it responds to the global competitive marketplace.

Composites Technology at the Associate Degree Level

At the technician's level, a more hands on approach to both composite materials and manufacturing methods should be emphasized. Modern composites manufacturing companies are seeing a more specific need for technicians capable of understanding the design processes utilized with composite structures and applying them to actual hands on manufacturing methods. Technician should have a working knowledge of how composite components are designed in order to assure that the manufacturing process is following the specific design specifications. Critical issues involving resin storage/mixing, fiber placement/orientation, and application/curing techniques are all key to a successful composite structure. Technicians working with composites must be able to bridge the gap between engineering composite design and the appropriate composite manufacturing method. The following list represents a basic body of knowledge that would be core to any instructional curriculum involved at the Associate of Applied Science (AAS) degree level for composites education and training. In general, the content items highlighted are suggestions for inclusion within a related course outline involving that particular composites subject area.

- Interpreting composite specific engineering drawings
    A. Both basic and geometric dimensioning and tolerancing (GD&T) criteria
    B. Lay-up notation (textile terminology – warp face/direction – fill direction)
- A basic understanding of the characteristics of composite materials to include resins or matrix types and fibers/forms

A. Thermoset resins (epoxy – polyester – cyanate esters - bismaleimide - polyimides)
B. Fibers (glass – aramid – carbon/graphite)
C. Fiber forms (filament – strand/tow/end – roving – fabric – prepreg – tape)

- A basic understanding of composite material mixing and processing methods and tools along with safe handling requirements
    A. Manual and automated resin mixing equipment/tools
    B. Cutting and trimming methods/tools
    C. Material Safety Data Sheets (MSDS) and OSHA regulations
- Specific composite manufacturing methods
    A. Process Selection
    B. Process methods
        1. Contact Molding
        2. Vacuum Bag Molding
        3. Compression Molding
        4. Resin Transfer Molding
        5. Pultrusion
        6. Filament Winding
        7. Tape Laying/Fiber Placement
    C. Machining Concerns
    D. Tooling and Design Considerations
- Inspection, testing and quality assurance of composite components
    A. Visual Inspection (nondestructive)
    B. Physical Tests
    C. Chemical Tests
    D. Mechanical Tests (destructive)
    E. Quality Assurance (facility – staff – materials – processes)
- Repair and rework of composites
    A. Types of damage
    B. Generalized Repair Methods
    C. Typical Repair
    D. Developments in Composites Repair

The following course titles would be inclusive of the above referenced subject areas and would represent the composite course offerings in an AAS Composites Technology program.

First Year :	Second Year :
Introduction to Composites	Composites Manufacturing Methods
Composites Safety	Fundamentals of Composite Design
Composite Drawings and Specifications	Composites Quality Assurance
Composite Materials and Testing	Repair of Composite Components

At the AAS level, the composite specific courses would have both theory and strong hands on laboratory experiences to support the lectures. A basic course in statics and strength of materials would also be most useful in understanding the basic engineering design principals. General education courses in algebra, geometry, trigonometry, oral and written communications would serve as academic pre-requisites. With an overall emphasis on the hands on applications of composite materials and manufacturing methods, labs should be well ventilated with plenty of work space and storage areas for the various composite materials.

By continually seeking the advice and input of a strong industry advisory board the composites curriculum should maintain its currency along with the potential for donations of both materials and processing equipment. Through a comprehensive composites curriculum at the AAS degree level; trained and well-qualified technicians will continue to advance the industry with both product and productivity improvements.

Undergraduate Composite Materials Course

For engineering and engineering technology students who are not pursuing a major in composites technology there should be a well defined and comprehensive single course in composite materials, methods and applications. Such a course would be especially significant for all mechanical and manufacturing related disciplines. As previously stated, there exists a shortage of engineers, technologists and technicians that understand how and why composites are used. Therefore, in order to better expose them, a stand-alone specific course on composites would be introduced within their disciplines and degree plans. Graduates with little knowledge of composites will not be able to assist with advancing the development of products and processes. This will ultimately create voids between new creative product designs and associated manufacturing applications. Students with a broad educational base in composites will better develop as participatory agents of change beyond the boundaries of traditional product and process designs and applications. A composites specific course will go a long way in helping to achieve this and will broaden the horizons as to the future potential of these materials.

The course will need to have both lecture and lab components to achieve the necessary objectives. The emphasis should bring together the three core ingredients as previously mentioned; materials, manufacturing methods, and design.

A typical one semester course outline is shown below.

I. Introduction to Composites
II. Safe Handling of Composites
III. Composite Matrix Materials
IV. Composite Reinforcements
V. Mechanical Properties
VI. Manufacturing Methods
VII. Fabrication and Assembly
VIII. Testing and Quality Assurance
IX. Damage Control and Repair
X. Composite Applications and Design

The lectures must be supplemented by hands on activities in a lab, thereby allowing the students to grasp the totally different methods and processes associated when working with composite materials and structures. Basic hand lay-up and processing methods can be utilized, but eventually more specific processes should be included, such as vacuum bagging, autoclave use, resin transfer molding, and filament winding. Safe material handling should also be emphasized both in the classroom and in the lab. Off campus learning experiences to composite related companies would also greatly enhance the students understanding of the materials and processes. The more students learn about composite materials the more likely they are to transfer that knowledge to other related engineering mechanics and design courses, which typically include only the more traditional materials within their problem solving exercises.

Conclusion

Education and training within a field that spans disciplines and is changing so rapidly can be both complex and challenging. Composite related programs are needed at both the baccalaureate and associate degree levels within engineering and engineering technology disciplines. There also exists a need for more composites coverage within other engineering programs such as the mechanical and manufacturing areas of study. This will help to ensure that there will be enough engineers, technologists and technicians to meet the future needs within the composites field. Many opportunities and paths exist at all levels to improve the entire composites education and training of these future graduates. I have identified several curriculum plans that might help to achieve those goals of updating and developing more widespread approaches to modern composites education and training. It is hoped that through these plans, the field of composites technology will continue to expand and improve the ways and means by which we live our daily lives.

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