Using an Undergraduate Materials Research Project to Foster Multidisciplinary Teaming Skills

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Abstract

This paper describes the use of undergraduate materials multidisciplinary research projects as a means of addressing the growing industrial demand for graduates experienced in working in multidisciplinary teams. It includes a detailed description of a project in which a multidisciplinary team of chemical engineering and civil engineering students analyzed the influence of epoxy selection and fireproofing on polymeric fiber-wrapped concrete members exposed to various heating cycles. Student activities included: identifying potential safety hazards, developing a detailed literature review, formulating a budget, planning and scheduling a year-long project, casting and wrapping concrete cylinders, designing the experimental plan, failure testing each cylinder, performing data analysis and developing conclusions regarding the processing variables. By combining their unique knowledge and abilities, the multidisciplinary team was able to resolve a technical problem that neither group could have solved independently.

Introduction

Both industry (1-4) and accreditation agencies (5) agree that teamwork and communication are among the top skills needed by new engineering graduates. Building on this idea, the Council for Chemical Research Education Committee (6) proposes that

- New chemists and chemical engineers must have the opportunity for a broader exposure to other areas of science and engineering to foster interdisciplinary and collaborative research,
- Communication skills of all types – oral, written, computer, and group dynamics – must be more heavily stressed,
- "Soft Skills" must be more strongly incorporated into the curriculum. These areas include the environment, team working, economics and the corporate/university structure.

The importance of multidisciplinary learning also has been re-emphasized by the Wingspread Group on Higher Education (7) who stated that the workers of the 21st century must possess "cross-functional interdisciplinary knowledge, skills and attitudes." Despite the growing consensus about the importance of multidisciplinary teaming experiences, faculty struggle to work these experiences into already crowded curricula. For example, the typical chemical engineering curriculum in the United States averages 133 credits (8). Many universities are responding to this challenge by introducing multidisciplinary laboratory or design courses (9,10). At Rowan University, a method of addressing these diverse challenges while also implementing pedagogical valuable hands-on learning experiences (11,12) and technical communications (13-15) has been developed.

At Rowan University, all engineering students participate in an eight-semester course sequence known as the engineering clinics (16). A summary of these clinic projects is provided in Table 1. In the Junior and Senior years, these clinic courses involve multidisciplinary student teams working on semester-long or year-long research projects led by an engineering professor. Most of these projects have been sponsored by regional industries or through government grants. Every engineering student participates in these projects and benefits from hands-on learning, exposure to emerging technologies, industrial contact, multidisciplinary teamwork experience, real-world application of classroom learning, and practice in technical communications.

Materials science and engineering projects lend themselves especially well to this format. These projects are inherently multidisciplinary as all four traditional engineering disciplines (chemical, civil, electrical, and mechanical) have specific interests and expertise in materials. These projects attract student participation and are comparatively simple to find and perform.

Project Case Study

In this project, a multidisciplinary team of chemical engineering and civil engineering students analyzed the influence of epoxy selection and fireproofing on polymeric fiber-wrapped concrete members exposed to various heating cycles. This project was sponsored by Fyfe Company, a manufacturer of fiber wraps and construction materials and was supervised jointly by one Chemical Engineering professor and one Civil and Environmental Engineering professor. Typically, every junior- and senior-level engineering student attends a presentation

Year	***Engineering Clinic Theme (Fall)***	***Engineering Clinic Theme (Spring)***
Freshman	Engineering Measurements	Reverse Engineering
Sophomore	Written Communication and Design	16-Week Multidisciplinary Design Projects and Oral Communication
Junior	Year-Long Multidisciplinary Industrial Research Projects	
Senior	Year-Long Multidisciplinary Industrial Research Projects	

Table 1. Overview of course content in the 8-semester Engineering Clinic sequence.

describing all projects available within the college. Each student submits a ranked list of five preferred projects and is then assigned to a project by a faculty team. The teams meet twice weekly for three hours at a time. Most projects last for one academic year.

The student team interacted regularly with both the industrial sponsor and the faculty supervisors to plan the scope and goals of the project. Early on the multidisciplinary student team developed a Gantt chart to help them organize their time and schedule the project. In a program such as this, the scope of the project must be limited so that a diligent student team reasonably can complete the project in either one semester or one year while ensuring that the primary goals of the industrial sponsor are met. Direct faculty involvement during this phase of the project is essential.

Ultimately, the students, faculty, and sponsors agreed on a pilot study to determine the effects of elevated temperature on concrete cylinders wrapped with glass fiber reinforced polymeric (GFRP) composites. The students developed an experimental design that would enable them to examine the influence of the fiber wrap on the compressive failure of cylinders that had been heated to a variety of temperatures. They also would examine the influence of a supplemental fire protection treatment.

The pilot study consisted of compression tests on eight series of 200-mm diameter by 400-mm high externally reinforced concrete cylinders. All of the specimens were cast from a single batch of concrete and cured under identical conditions. A moderate strength concrete mix was used with a compressive strength of approximately 40 MPa. The cylinders were reinforced in the hoop direction with two continuous layers of Tyfo® SEH 51 reinforcing fabric applied with Tyfo® T two-part epoxy. The seam was wrapped an addition 50-mm beyond the completion of the second layer. The system is very similar to the commonly used Tyfo® S or SEH-51 composite system but with a modified epoxy for higher temperature applications. Two sets of cylinders were treated with a Tyfo® FC/F fireproofing coating and paint. All reinforcement and protective coatings were applied following the manufacturer's recommendations by the same technician. Typical properties of the composite are provided in Table 2.

Following a test plan based on an experimental design developed by the students and approved by the faculty, sets of four cylinders were then heated for 90 minutes in an electric oven to temperatures up to 185° C. Oven temperatures were monitored closely because of an initial temperature drop that occurs when the mass of concrete is introduced to the oven. Direct exposure to flame was not considered because it was known that this would simply burn off the composite system. Preliminary tests with coupons of the composite indicated the particular system under consideration would degrade well below 300° C.

The cylinders were allowed to cool to ambient temperature, were capped, and then tested in compression to failure. Heating and testing of cylinders did not occur until the concrete had aged six weeks. The cylinders were tested the day after they were

PROPERTY	ASTM METHOD	TYPICAL TEST VALUE
Primary E-Glass Fiber		
Tensile Strength	D-2343	2068.3 MPa
Elongation at Break	D-2343	81.3 mm
Tensile Modulus	D-2343	72.4 GPa
Polyaramide Fiber		
Tensile Strength	D-2343	2757.8 MPa
Elongation at Break	D-2343	60 mm
Tensile Modulus	D-2343	124.8 GPa
Composite Laminate		
Ultimate Tensile Strength in Primary Direction	D-3039	575 MPa
Elongation at Break (min)	D-3039	2.2%
Tensile Modulus	D-3039	26.1 Gpa
Ultimate Tensile Strength 90 degrees to primary fiber	D-3039	34.5 MPa
Laminate Thickness		1.3 mm

Table 2. Typical properties of Tyfo® SHE-51 Composites (17, 18)

Cylinder Number	Wrap	Fire Protection	Temperature (°C)	Failure Mode	Ultimate Stress (MPa)	Group Average	Ratio vs. Wrapped at Ambient Temperature
1	N	N	21	-	42.23	39.93	0.38
2	N	N	21	-	38.89		
3	N	N	21	-	38.66		
4	Y	N	21	LFR	96.99	104.31	-
5	Y	N	21	LFR	106.33		
6	Y	N	21	HS	102.29		
7	Y	N	21	HS	111.64		
8	Y	N	120	SD	107.57	102.30	0.98
9	Y	N	120	LFR	90.51		
10	Y	N	120	HS	103.3		
11	Y	N	120	HS	107.84		
12	Y	N	135	HS	105.42	100.24	0.96
13	Y	N	135	SD	101.50		
14	Y	N	135	HS	95.87		
15	Y	N	135	HS	98.17		
16	Y	N	150	SD	91.83	91.13	0.87
17	Y	N	150	LFR	84.73		
18	Y	N	150	SD	91.98		
19	Y	N	150	AS	95.97		
20	Y	N	180	SD	85.49	85.19	0.82
21	Y	N	180	SD	88.12		
22	Y	N	180	SD	81.34		
23	Y	N	180	SD	85.79		
24	Y	Y	150	LFR	102.48	101.13	0.97
25	Y	Y	150	HS	109.97		
26	Y	Y	150	LFR	95.83		
27	Y	Y	150	VS	96.23		
28	Y	Y	185	HS	96.32	93.5	0.90
29	Y	Y	185	LFR	85.82		
30	Y	Y	185	HS	93.48		
31	Y	Y	185	HS	98.36		

VS = Vertical Split, LFR = Localized Fiber Rupture, AS = Angled Split, HS = Hoop Split, SD = Seam Debond

Table 3. Experimental Plan and Results from Case Study

heated and all testing was completed over a four-week period. Loading was performed using a hydraulic testing machine under load rate control. A detailed test plan is provided in Table 3.

The students performed all aspects of the materials preparation, testing, data analysis and reporting. Their results are shown in Figure 1. The students were able to observe and categorize failure modes as being through Vertical Split (VS), Localized Fiber Rupture (LFR), Angled Split (AS), Hoop Split (HS), or Seam Debond (SD) as defined by Karbhari and Howie (19). Local fiber rupture is characterized by fracture of the hoop direction fibers in a localized area accompanied by a bulging of crushed concrete behind the composite. Vertical splits and angled splits are also fiber rupture phenomena however the fiber failure propagates over a greater distance. Hoop split is characterized by horizontal splitting of the wrap between bundles of primary hoop direction fiber. This breaks the reinforcing wrap into a structure of bands rather than a continuous sheet. Failure occurs when an isolated band then ruptures. Seam debonding is characterized by separation between the two layers of wrap. The separation starts at the seam and

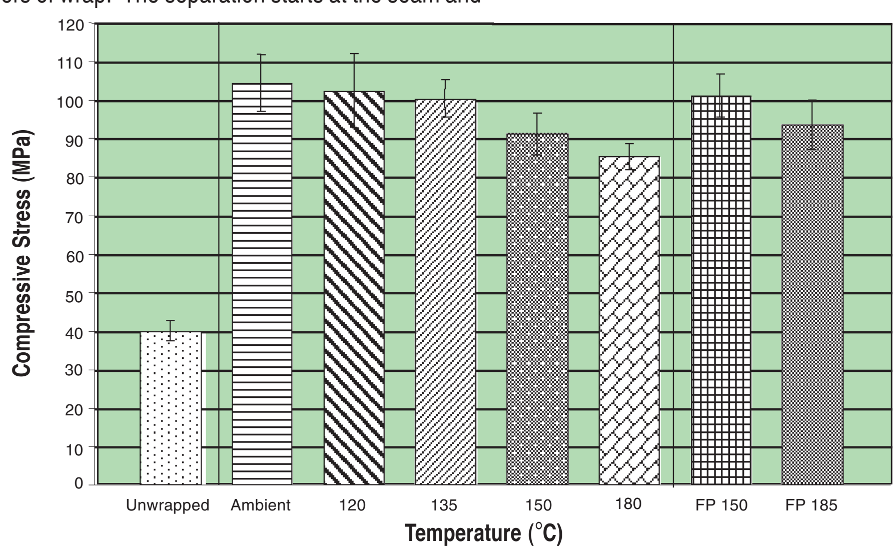

Figure 1. Results of thermal studies of a Tyfo® external reinforcing system.

continues as a shear failure between the layers. This effectively cuts the confining capability in half, leading to specimen failure.

These various failure modes are shown in Figure 2. Figure 3 shows photographs of typical failures in this study.

Both the chemical engineering and civil engineering students had to develop a familiarity with the nomenclature and literature in the field. Moreover, they were able to blend their unique backgrounds to address issues that neither group had the background to deal with independently. The civil engineering students were familiar with concrete, testing columns, and modes of failure, while these concepts were quite new to the chemical engineering students.

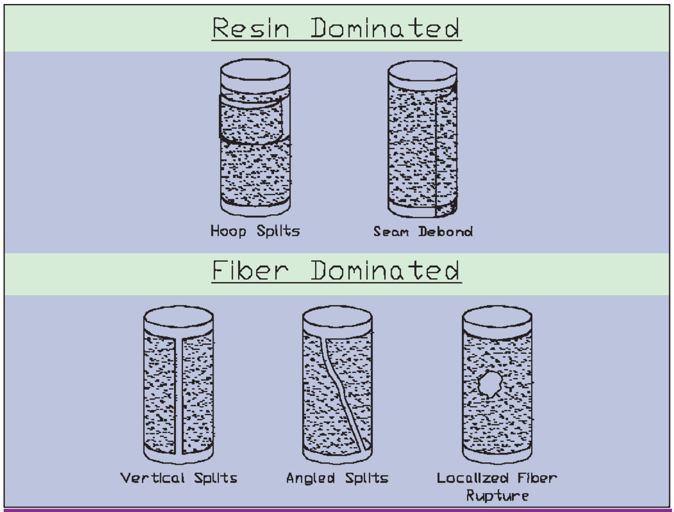

Figure 2. Examples of cylinder failure modes (adapted from Karbhari and Howie, 1997 [19])

Both fiber-dominated and resin-dominated failure modes were observed in the unheated control group. Two specimens failed due to localized rupture of the fibers in the hoop direction and two specimens failed with a hoop split. Inspection of the failed specimens revealed that good bond remained between the composite and the concrete. The results show the FRP reinforcing system increased the compressive strengths of the concrete cylinders by approximately 255%. This result is consistent with the manufacturer's design criteria [18] which predicted an increase of 222%. This consistency provided a strong indication the wrap application and testing methods was satisfactory. As expected for the tested wrap architecture, the strengthening mechanism can be directly related to the confining stress provided by the composite reinforcing [19]. This provides a strong indication the wrap application and testing methods were satisfactory and that the students had developed a thorough understanding of the testing procedures.

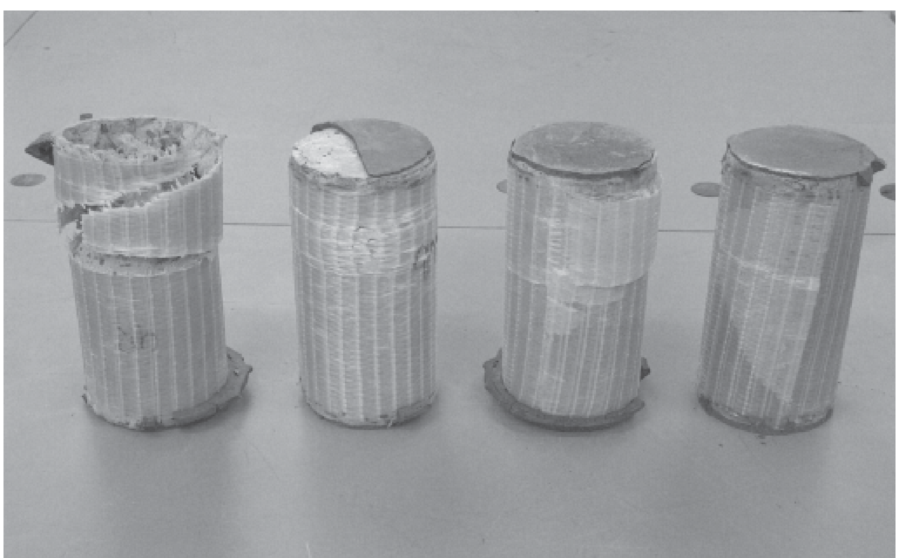

Figure 3. Typical cylinder failures. From left: angled split, local fiber rupture, hoop split, seam debonding.

Through this point in the study, the civil engineering students led the chemical engineering students through the stages, leaving some of the students questioning the value of their contribution to the project. That changed when the data were examined more closely. Slightly elevated temperature (~60∞C) typically accelerates the reaction rate associated with the curing of the epoxy. However, as the temperature nears the glass transition temperature (T_g) of the epoxy, the resin begins to lose its glassy character and gradually becomes more rubbery. Therefore, the civil engineering students expected to see a substantial loss in strength above the glass transition temperature of the epoxy.

The glass transition temperature of the epoxy used in this study was 121°C. Even at a temperature of 135°C, only a 4% loss of strength was observed. This loss was not statistically significant. By contrast, cylinders heated to 150° C showed a 13% reduction in strength and seam debonding replaced hoop split as the predominant mechanism of failure.

The chemical engineering students observed that the glass transition temperature does not imply a sudden shift from a non-deformable solid to a suddenly malleable material. Instead, T_g represents the onset of segmental mobility. Even at temperatures above T_g, the degree of segmental mobility remains highly dependent on chain stiffness and intermolecular forces. They concluded that at some temperature greater than T_g, the stresses associated with the differential thermal expansions of the concrete and epoxy become sufficient to disrupt the bonding between the fiber. This conclusion would not have been reached by either group acting alone, but rather resulted from the positive interdependence of the multidisciplinary team.

In addition to the technical exposure and the interaction with the faculty supervisors, the students were forced to interact with members of the university community beyond their normal contacts. For example, the students made arrangements with the art department to use their large kilns for an initial coupon study. They met with faculty in the mathematics department to discuss experimental designs and interpretation of experimental data. They also arranged for shipment of the fiber-wrap material with the company.

Because the scope of the project was limited, the students were asked to make recommendations regarding the next phase of the project. Although the students would not be able to perform the subsequent experiments themselves, the faculty believed that planning the next phase was an essential part of the research experience. The students recommendations included the following:

- Examine reinforcing systems from a wider variety of manufacturers, possibly including different materials
- Perform more trials at each test level to reduce the effect of experimental error and insure reproducibility
- Perform more detailed coupon tests to evaluate properties of the reinforcing composite (prior to installation on the test cylinders)
- Examine additional fire protection systems and try a larger experimental range of data for the current system
- Perform beam tests to evaluate a different stress state

As a culminating experience for this project, the student teams gave a pair of technical presentations. The first was a traditional oral presentation in which the team introduced the project, summarized their experiments, showed key results, summarized their findings and addressed questions from the audience. The presentation was given to a room of civil engineering students and a mix of civil and chemical engineering professors. The second presentation was a poster presentation given externally at the Ninth Annual Uni-Tech Conference in Newark, New Jersey. The student team won an award for the best student poster presentation. Additionally, the final written report received a best paper award in a regional competition sponsored by Materials Testing Inc.

Summary

As engineering programs search for new ways to meet the increasing demands from industry, accrediting boards, and the students themselves for more practice in teaming and greater exposure to research, materials projects provide an ideal method of delivering all of these things in a crowded curriculum. Students involved in the case study described in the paper gained exposure to an emerging technology area, worked in multidisciplinary teams, and developed both their technical and "soft skills". Additionally, the students saw how engineers from different disciplines could combine their skills sets and knowledge bases synergistically to solve a problem beyond the range of either group acting alone.

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