Composite Column Design/Test Lab

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Abstract:
This research incorporates engineering design (using smart spreadsheets) into a laboratory activity focusing on columns made of composite materials.

In previous work, a laboratory activity was developed supporting composite design of polymer matrix composite beams[1]. The present work applies a similar, expanded approach to ceramic composites in the form of columns.

In the lab, students simulate composite columns and use a smart spreadsheet to help optimize their design for engineering performance, including 'specific' properties. Parameters are discussed and evaluated before the column is made. The composite is then fabricated. Finally, the composite is tested and the experimental data ('critical load' for columns) is compared to predictions.

Module Objectives:
Upon completion of this activity, students will be able to
1. Design an appropriate composite column structure, model the composite structure, optimize the composite structure design, and subsequently predict its performance.
2. Fabricate the composite using an appropriate method and test the composite for critical parameters.
3. Critically evaluate the composite's performance with reference to the predictions, testing methods, and appropriate literature data.

MatEd Core Competencies Covered
0.B Prepare tests and analyze data
1.A Carry out measurements of dimensions and of physical phenomena
3.B Demonstrate use of computer applications
7.J Demonstrate how materials properties are used in engineering design
11.A Describe structure and advantages of composite materials
11.B Explain basic processing processes for composites
16.A Explain effects of processing and manufacturing variations on material properties

Key Words:
Composites, Column Design, Spreadsheet Optimization

Type of Module/Mode of Presentation: This activity includes in-class, demo and lab aspects.

Time Required:
This is a multi-faceted project-based activity, requiring 2-3 weeks duration with 3-5 class interactions depending on curricula, and infrastructure for fabrication & testing.

Prerequisite Knowledge:
Students should be able to 1)use spreadsheets, 2)have basic knowledge of both structures (beam bending and columns) composites and composites structures, and 3)have the logic and math skills necessary to plan and quantify the composite design and optimization process.

Target Grade Level(s): This activity is oriented to Grades 13-16 (undergraduate college).

Table of Contents:

Equipment and supplies needed:
Modeling: spreadsheet and platform, access to composite properties, knowledge of composite design/mechanics, knowledge of column design and failure (buckling)
Fabrication: ceramic composite matrix and reinforcement (continuous/discontinuous), processing facilities (press, vacuum, etc.)
Evaluation: compression testing (size dependent), dimensional measurement (modal description)

Curriculum Overview and Instructor Notes:
Depending on student background, resources and curricula requirements, the instructor may wish to modify any of the elements in this work. This includes the design tool (e.g. FEA vs. spreadsheet), fabrication (e.g. press vs. vacuum) and evaluation (e.g. testing methods and equipment).

This work specifically targets the design, fabrication and evaluation of composite columns in support of the program curricula. While an overall need may exist to target wide array of composite applications, this effort is realistic for the resources available, and our curricula needs.

In this traditional composite lab approach; composite beams and columns are designed, their stiffness is predicted, and they are mechanically tested. Tensile testing (three-point) beams is more suited to polymer matrix composites than ceramics (with a pardon to all the bridge decks vs. columns out there). So the Plastics and Composites course uses beams, and the Ceramics and Composites uses columns, as target structures. In a previous effort, a smart spreadsheet was created specifically to solve for three-point bend stiffness of a layered polymer composite in support of Plastics and Composites[1]. The current effort focuses on column design for the Ceramics and Composites course, but also endeavors to include an optimization routine targeting 'specific' properties (e.g. stiffness per weight).

In the ceramics class, compression testing allows a brittle material to survive longer than tensile tests. Bend tests are conventional for many bridge applications, but they are done in the Ceramics and Composites course. For diversity, and other attributes, compression testing is the primary focus for the ceramics course. Most students do not engage often in structural design regarding compression. Most students are introduced to 'column design' as an example. Introductions usually occur in a 'Strength of Materials' course[2]. Thereafter, information may be found in some 'Machine Design' course[3]. Typical engineering handbooks[4] also summarize column design, and relate the variety of analytical approaches. There are numerous 'critical load' equations for different materials (e.g. steel vs. aluminum) and different lengths (e.g. 'short'-Euler vs. 'long'-Johnston).

In practice, the predominant method for design of any sort is numerical, and could be applied to this work. On a recent peruse of the internet, a site was found that listed many numerical analysis programs that are available[5]. But because of the education level of interest in this lab, all design analysis was constrained to analytical. This both reduces costs (for licensing the numerical programs) and emphasizes the parametric nature of what affects the performance of these column structures. So the use of this spreadsheet is simply one way to support design.

For this paper, two critical load calculations have been included (long and short). Euler is used for a 'long' column, and a Graphite/Epoxy (Gr/Ep) relation from Jones[6] is used for a 'short' column. This illustrates the extreme variability of predictions. A number of parameters are key to the success of this type of structural design, and are implemented in this lab. These parameters include geometry, volume fraction and loading. The effect and importance of various composite parameters on mechanical behavior can be hard to grasp. Since traditional hand analyses are cumbersome and prone to error, the use of 'smart' spreadsheets is appropriate. Hand analyses are also not very friendly to relational analyses and optimization. This lab uses smart spreadsheets to alleviate these issues (example attached). An excerpt of the lab is shown below:

Module Procedure:

Instructions: Note: Please observe lab safety policies during this activity.

The plan: Everyone should make two columns: one homogenous and one composite (though a two person team can make two sets). Our immediate objective is to design the column. We will spend a class session on this part of the lab. Start by writing design requirements and constraints. For example, we will test the columns on the Tinius Olsen. The plattens will be vertically oriented, and the columns should not exceed a foot tall. Available materials include concrete, wood core, fiberglass, epoxy, graphite, honeycomb, etc. (in HT212), one of which must be a ceramic).

The next step will be to predict the properties for each individual column. Custom Excel™ spreadsheets have been created to assist your analysis (attached). The geometry is limited to traditional column analysis (see Hibbeler or Beer & Johnson or Mott). Create a design and input the appropriate geometry and material properties. The spreadsheet will calculate the resulting radius of gyration, slenderness ratio and critical load (mode one deflection caused by free-end loading).

Each student (or team) will have to research and decide on a design, material, and forming method for their columns. Specify a column-geometry (suggested length of about 12", width and thickness less than 1"). You must select a composite material and lay-up design, and then construct the column. We have a hot press, vacuum bags, and even an RTM (resin transfer molding) system.

We will then test the columns and compare their experimentally measured properties (critical load) to the calculated load. The Tinius Olsen is a tensile/compression tester on which can you measure both the load and the resulting deflection (to detect mode one initiation).

You will have to plan your activity due to time constraints. Check your schedule and plan for the testing needed. We will do a preliminary compressive test on a column of simple wood core, so that you'll have a clue of what to expect during the testing of your column. We don't have to break the column, only initiate 'mode one' deflection. We're trying to predict the critical load on the column. A requirement is that you predict the structures' behavior before you test it.

After you have tested the column, compare your prediction with your test data, and also what is in the literature (if possible). Comment on how close your values are (in percent), as well as reasons that explain your results. For example, your predictions may have assumed a more favorable fiber volume or material property than actually existed in your structure.

The attached spreadsheet has areas for 'input' (gray shaded) and areas for 'calculated values'. It generally flows from top-to-bottom, and data is entered sequentially.

Author Comments:
An integral part of the lab is the use of the spreadsheet to optimize the column design and predict properties, while alleviating problems with computational errors. This assumes that the students have the basic knowledge of structural design. Students should be aware of various types of loading, moments of inertia, and important design criteria. In the case of a column, this means that they are cognizant of short vs. long column criteria, and can understand critical loads (Pcr).

An introduction to the spreadsheet and some of its features is typically needed (depending on the class response). The spreadsheet has multiple 'sheets'. Some input cells have limits that reflect real bounds on the value. Comments are written in the right column. So in-class demos of various input and resulting outputs are used to show the design and optimization process.

The spreadsheet is used during class to promote discussion, and is also available on BlackBoard™ for off-line reflection. There is a requirement that a spreadsheet (with predictions) is to be submitted before testing can occur. The goal here is to avoid the trap of students wanting to build the 'strongest' column, but try to key their interest to building the most 'predictable' column.

The composite structure fabrication aspect of the lab depends on the resources of the institution. Simple pressure (gravity) is appropriate, though various bag technologies are nice. This is the reason that the Pcr equations are tailored to a composite sandwich structure.

Testing is also dependent on available resources. A tensile/compression tester is a common tool for evaluating structures. A simple dial-gage is typically used to measure lateral displacement, though a light profile has also been employed. Only the critical load is recorded for comparison to the predicted value.

During the 2-3 weeks that the activity occurs, student work is handed in regularly. Initially, effort is directed at model creation and performance prediction. This culminates in the student handing in the necessary documents for each. The model is drawn, with relevant composition and fabrication information. The prediction requires the student hand in a spreadsheet (evidence) with its relevant information.

The second phase of work evaluated is the composite structure itself. Previously the students have been in the lab applying their knowledge of ceramics and composites with regard to both manufacture and characterization. By this experiment, they demonstrate their abilities to fabricate a structural column that matches their proposed model. The instructor can compare geometry and other composite parametric information.

The final phase of effort involves the testing and comparison of composite column performance. Students hand in a lab report that includes evaluation of the design process, including statements directed at sources of error and remediation techniques.

The completeness and sequential aspect of this laboratory allows for multiple assessments. As the students interact with both theoretical and experimental aspects of composite design, the instructor can track progress and remediate concerns. Multi-step labs are easier to grade (in parts). The lab can also address objectives pertaining to communication and continual learning, with specific metrics. For example, the preliminary design work can be graded individually, but the beams could be fabricated in teams and assessed for that objective.

Student comments overwhelmingly state their attraction to this lab. Some students are unfamiliar with the use of spreadsheets and the design process, but fabricating structures and subsequent testing is very attractive and engaging. Since the course uses BlackBoard™, many students download the spreadsheet and work off-line and off-hours[7]. This is also a plus for engaging students in the process.

Outcomes associated with this laboratory address higher-order learning (e.g. Bloom's taxonomy, design). This may be useful in meeting the needs of ABET outcomes. Specific metrics for design have not yet been created for this purpose, but the effort is planned for the future.

Supporting Materials
Please refer to the attached spreadsheet (referred to in the text)

References

1. Johnson, C.H., "Modeling in a Composite Beam Lab", ASEE Annual Conference, 2002.
2. Hibbeler, R.C., "Mechanics of Materials", Prentice-Hall.
3. Mott, R.L., "Machine Elements in Mechanical Design", Prentice-Hall.
4. Avallone, E.A., Baumeister III, T., "Marks' Standard Handbook for Mechanical Engineers", McGraw-Hill.
5. HYPERLINK "http://www.structural-engineering.fsnet.co.uk/free.htm" http://www.structural-engineering.fsnet.co.uk/free.htm Last updated: 21 May 2006.
6. Jones, R.M., "Mechanics of Composite Materials", Scripta Book Company and McGraw-Hill.
7. Johnson, Craig, "BlackBoard™ MET382 Course Statistics", Central Washington University, 2006.

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Evaluation Packet

Student evaluation questions (discussion or quiz):

1. What are the principal criteria needed in the design of a composite column?
2. What are the principal criteria used in the fabrication of the column?
3. What test methods can be used to test the column?
4. What criteria did you use to evaluate column performance?
5. Explain any deviations you observed between design criteria and actual test data.

Instructor evaluation questions (for the instructor):

1. Did the activity work as presented? Please note any problems or suggestions.
2. Was the background material on steels and titanium sufficient for your background? Sufficient for your discussion with the students?
3. Did the activity generate interest among the students?
4. Please provide other comments or suggestions for this activity.

Course evaluation questions (for the students)

1. Was the activity clear and understandable?
2. Was the instructor's explanation comprehensive and thorough?
3. Was the instructor interested in your questions?
4. Was the instructor able to answer your questions?
5. Was the importance of materials testing made clear?