Economical Classroom Laboratories for Material Science

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Abstract – Material Science is most economically taught between four walls with a chalkboard but the results are questionable. The most effective approach includes a laboratory experience using dedicated laboratory equipment and space. This paper presents an intermediate approach with the details of five laboratory exercises performed in the front of the classroom. The activities demonstrate very practical material properties and teach laboratory writing skills. The demonstration labs involve the students and are specifically designed to help the students grasp the mathematics used to characterize materials. A brief history of the laboratory development is included along with a summary of the pedagogical results to date.

Keywords: material science, laboratory exercises, thermal expansion, stress/strain, bending.

INTRODUCTION

This paper is introduced as a historical narrative in the first person. I began a formal study of Material Science in 1976 and have taught the topic since 1986. Over the years of teaching I began to discern various patterns of learning deficiencies among the students. Some topics students could grasp with ease while others were more difficult. The first difficulty observed, concerned the simple relationship between stress and strain. Students did not really understand the elastic to plastic transition point, what the elastic modulus represents, and had trouble with simple algebraic solutions to applied problems. I introduce a series of supplemental work sheets for them to practice their algebra while learning how to use material properties for design. This improved their algebra proficiency but not their grasp of fundamental material properties. I finally decided to attempt a simple demonstration experiment to explain the elastic modulus. This experiment proved to be very successful and has developed into a series of five laboratory experiences which are described in fully in the body of the paper.

Fifteen years ago this course incorporated traditional "hands on" laboratories but space and financial constraints and increased class size forced me revert to "four walls and a chalk board"; but that is a topic for a different paper. The concept of a demonstration lab was foreign to me. All good labs were done in person by the student, but this new method proved to be successful. Students emitted the wonderful "ah ha" of comprehension that we educators so love to hear. The first laboratory reviled a new deficiency; many students had not mastered simple lab write ups. A practice lab, thermal expansion, was introduced to teach students how to write a lab report. The third and forth labs were an off-shoot of some professional material testing for Kincaid Furniture, one of our local manufacturers. An additional lab was added to emphasize a very simple point that has bothered me for many years. Students inevitably interchange the terms force and stress. In frustration I replaced the first lab with this elementary, physical science experiment to differentiate the concept of stress and force. This lab, serendipitously, has proven to be superior for teaching lab writing format. Evidently, thermal expansion was more difficult to comprehend then I had presumed.

Laboratory thematic

The labs described in this paper meet a theme of simplicity by design. The labs use common materials for test specimens, and minimal testing equipment. This theme has the additional benefit of being affordable. The focus of this set of experiments is comprehension of concepts, not precise measurements. The students perform the experiments themselves with materials that they can relate too. The labs are portable and designed to fit into a regular classroom. The teacher should remember to mention appropriate safety precautions before allowing students to perform the experiments. The first lab is elementary and used to teach students how to write a lab report.

First lab, Simple Stress

Teaching Material Science primarily consists of explaining the properties of materials and their application. In order for students to understand the material properties they have to first understand the terms used to characterize the properties. Stress is one of the principle terms used to describe a material. The materials ultimate and yield strength are expressed as a stress in force, per unit area [1]. Students have a fair understanding of force but some have difficulty understanding ratios such as force per area. The first lab attempts to make this relationship very clear. Students use a bathroom scale to measure the force of an object as its weight and a tape measure to determine the area. A two by four stud is used as the test specimen for this experiment. The specimen has to be of sufficient weight to be measured within the resolution of the scale and of unique enough dimensions to force the students to think about the calculation. The American structural wood industry is very successful at creating irregular dimensions. This lab is performed during a regular class period with ample time for explaining the write up procedure.

Second lab, Thermal Expansion

This simple laboratory experiment was originally used to teach students how to write a lab report. It fits much better as a second experiment where the focus is not on lab format. The lab consists of heating up a six inch long piece of quarter inch diameter aluminum rod. The rod was purchased from Lowes hardware cut with a hacksaw and filed to approximately six inches. The rod is heated with a heat gun, also purchased from Lowes hardware. The temperature is measured with a thermometer and the length is measured with a Mitutoyo, digital calipers. The experimental setup can be viewed in Photograph One. The purpose of the lab is to determine the coefficient of thermal expansion and compare it with the know value. The lab is used to teach the students quite a few concepts and skills. Students traditionally have trouble understanding the concept and use of a coefficient in a simple equation. The lab is used to show how the coefficients are determined and how they function in the expansion equation. In this case the equation used is: change in length equals the original length of the material times the coefficient of thermal expansion times the temperature change [2].

Equation one: $\Delta L = L\alpha\Delta T$

The students are required to tabulate and graph the data. Then perform a linear curve fit and determine the coefficient with the slope. The lab is performed in the front of the class with two students heating and measuring the specimen and one student recording data on the board. The specimen is heated in a small box to insure even heat distribution. The students have to move quickly to measure the length once the heat gun is removed. This lab has been conducted for a number of years and the experimental value is usually within a few percent of the know value. The value of this process is empowering the students to determine the coefficient and comparing their value with the know value.

Photograph One: Thermal Expansion Laboratory Setup

Third lab, Spring Coefficient

The third laboratory experience helps to demonstrate the elastic nature of materials and the relationship between applied force and stretch. This relationship is the unique spring coefficient for the test specimen [3]. The experiment is repeated with a longer and thicker specimen to demonstrate how the coefficient changes. The students are required to tabulate and plot the data and then calculate the coefficients. The actual purpose of this lab is leading students to eventually understand the stress strain diagram. The lab is performed with common materials, two inch rubber bands. Four rubber bands are preselected with the same stretch for a given load. The lab is performed by suspending the rubber bands from a hook mounted on a pole about three feet long. A Nalgene water bottle is attached to the bottom of the rubber band with a metal hook. The hook is formed by twisting sixteen-gauge wire around the throat of the bottle. A colored paper clip is attached to extend out past the hook and serve as a pointer. A ruler is taped to the pole for the displacement scale. Four students help perform this lab, one to record the data on the board, one to support the apparatus, one to add water in 150 milliliter increments, and one student to coordinate the activity and read the scale.

The experiment begins with a student zeroing out the scale by sliding it up or down the pole and affixing it with tape. Water is measured in a graduated cylinder and added to the bottle extending the band. The displacement value is read and recorded then the process is repeated an additional four times. The same version of the experiment is repeated with a different rubber band. This allows the students to grasp the idea of an average material property and the variation present with the bands being used. The experiment is repeated with two rubber bands in parallel and again with two rubber bands in series. A paper clip is used to connect the bands, end to end in series with a simple twist. The experiment produces very consistent results and is easy for the students to analyze and write up.

The correlation between a spring curve and the stress, strain diagram is made once the students finish the laboratory. The concept of stress being a distributed force is usually easy to explain, while strain being change in length divide by the original length is obscure. This spring curve experiment demonstrates how stretch is proportional to length. More importantly students can relate the elastic modulus very easily to the spring coefficient. The experimental setup can be viewed in Photograph Two.

Photograph Two: Spring Coefficient Laboratory Setup

Fourth Lab, Beam Stress

This lab and lab five both require a dedicated piece of equipment that can reside at the edge of a classroom. The lab was designed to help students understand the moment of inertia for beams in bending. This demonstration can be used equally well for Strength of Materials, Statics, or Engineering Mechanics. Stress due to bending is a combination of tensile, compression, and shear stress so the test is an easy way to demonstrate all three. Bending a beam is also the cheapest and easiest way to achieve the yield and ultimate stress for common materials. The conceptualization and realization of this experiment took a number of years. A local furniture company presented our department with a request to perform a series of bedrail static failure tests. This prompted the design of what one student nicknamed, The Beam Buster Five Hundred. This inexpensive frame, load application method, and load cell proved to be very satisfactory for breaking bed rails. The frame was then modified to break structural lumber as a demonstration lab.

The lab is built around the simplest bending equation-equation 3; simply supported, center load, [4].

Equation 3: Bending Stress, $S = MC/I$

Where S is the stress, M is the moment, and I is the moment of Inertia. M is the product of the center force and half the beam's length. C is half the height of the cross section of the beam, where the height is the cross sectional dimension in line with the applied force. I is the cross sectional base times the height cubed divided by twelve. This is the moment of inertia for a rectangular cross section, equation 4.

Equation 4: Moment of Inertia, $I = bh^3/12$

Any other shape beam could be used with this device but simple rectangular shapes are easy for students to work with for an introductory experiment. The experiment consists of bending a two by four stud until it breaks, recording the force, calculating the breaking strength, and comparing it with the expected values. A scale for measuring the tongue weight of a car/truck trailer is used as an inexpensive load cell. A scissors jack is used to apply the load because it is fast, clean, and cheap. The frame is made up of common lumber with guide rails to help keep the beam from twisting. The lab is exciting and fun for the students because they enjoy breaking material. The experimental setup can be viewed in Photograph Three.

Photograph Three: Beam Bending, Laboratory Setup

Fifth Lab, Beam deformation

This lab experience is similar to the forth lab with an emphasis on deformation. The purpose of this lab is to measure the deformation of a beam in bending and compare it to a calculated value using equation five [5].

Equation five: Deformation, $D = (FL^3)/(48EI)$

Where I is the same moment of inertia calculated in equation four. F is the center load, L is the length of the beam, E is the modulus, and A is the cross sectional area. The lab write up concentrates on comparing the experimental deformation with the value calculated using equation five. This lab provides an opportunity to discuss and use the deformation equation and a second chance for students to become immersed in the effect of beams subjected to a bending force. The accompanying classroom homework and lectures easily move from stress and deformation of the test beam to design and application of numerous beams, trusses, and bridges. This is a culminating point in the materials class. Students have spent a dozen weeks learning about the micro properties of materials and now can visualize how the micro properties affect the macro properties.

Discussion of lab choices

There are many laboratories and lab environments that teachers can choose to accompany a Material Science class. The labs chosen should complement and help explain the lecture subjects. The labs should be a positive experience for the students. The following observations are the opinion of the author based on more than twenty years of teaching Material Science. These critiques are not documented in the literature and can easily be disputed. The principle pitfall at many institutions is the attempt to use research level experiments to teach fundamental principles. The research is often beyond the student's elementary comprehension and creates frustration. A second common error is the use of specialized equipment and specimens to produce very accurate results. Students attempt to watch a technician operate a machine in a crowded room. The experience is often uncomfortable and confusing. Then the lab write ups are critiqued on nuances that guarantee distaste for the field of study. Instead of encouraging and nurturing a love of learning and specific understanding the experiences creates a learning barrier. Students associate the material characteristics with expensive testing machinery and don't grasp their simple application.

Conclusions

A Material Sciences class can be greatly improved by incorporating simple demonstration laboratory experiences. The laboratories provide a nice break from lectures. The labs allow students to visualize the relationship between material properties and physical changes. Specific labs allow the teacher to emphasize mathematical principles that the students struggle with. The choice and sequence of labs presented in this paper are conducive to student's comprehension of Material Science and hopefully lifelong learning.

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Biographical Information

David Domermuth is a professor at Appalachian State University. He has been teaching for 22 years. His career began in metals manufacturing, shifted to furniture, and now Industrial Design. David teaches the engineering aspects of product design. He has three degrees in Mechanical Engineering and has lived abroad for five years. David's current research is concentrated on gasification of biomass as a renewable energy source and using biochar for soil augmentation. His primary hobby is road biking with 30 years of riding in the Appalachian Mountains.