Using an Advanced Mechanics of Materials Design Project to Enhance Learning in an Introductory Mechanics of Materials Course

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Abstract

Design projects and experiments demonstrating mechanics concepts are two ways in which learning can be enhanced in undergraduate mechanics courses. This paper will discuss incorporation of these concepts in two mechanics of materials courses at the University of Wisconsin - Madison. Students in an Advanced Mechanics of Materials course were assigned a design project in which they created new table-top demonstrations and classroom experiments for the introductory level Mechanics of Materials course. The design project involved the development and construction of a table-top experiment or demonstration suitable for instruction in Mechanics of Materials. A written report, including instructions for use, descriptions of suggested demonstrations and experiments, and a thorough mechanics analysis of the device constructed, was required. In addition to providing the Advanced Mechanics of Materials students with a good open-ended design experience that reinforced introductory topics and helped the students to develop the advanced skills being studied in the course, some wonderful teaching demonstrations were created for the introductory Mechanics of Materials course. With a minimal supplies budget of $500, students created 9 projects, which addressed topics such as temperature effects, elastoplastic bending, and stress concentration. After the Advanced Mechanics of Materials course was completed, a guide was developed for instructors of the Mechanics of Materials course based on the students' project reports. In later semesters, the table-top demonstrations and classroom experiments served as a teaching aid in two introductory courses on mechanics of materials.

I. Introduction

Tabletop demonstrations and classroom experiments enhance student learning of topics such as mechanics of materials. Several such demonstrations and experiments have been used by the author during lectures for an introductory course in Mechanics of Materials. Student comments on course evaluations have been very positive about the educational value of these teaching tools. One student remarked that "Demonstrations are helpful, because you can see what's happening." After example problems, demonstrations are frequently cited as one of the most beneficial aspects of the class.

To enhance student learning in the introductory Mechanics of Materials course, additional demonstration devices were desired. In teaching a follow on course in Advanced Mechanics of Materials, the author posed the design problem of creating tabletop demonstrations and classroom experiments for the introductory level course in Mechanics of Materials that they had completed in the previous academic year (see Figure 1).

The 35 class members were divided into 9 teams. A topic area from the Mechanics of Materials course was assigned to each team. These topics were broad in nature and left the design project open ended. Students were asked to consider specific concepts that they struggled with and think about what would have enhanced their learning of this concept. In addition to the development of new teaching aids, it was intended that this design project serve to reinforce introductory concepts for the Advanced Mechanics of Materials students and build on the advanced skills being studied in this course.

Advanced Mechanics of Materials
EMA 506 Design Project
Fall 2000
Instructor: Prof. W.C. Crone, Engineering Physics

Mechanics of Materials TableTop Demonstrations and Experiments

Introduction

Your assignment is to create new tabletop demonstrations and classroom experiments for the introductory level class. A topic area covered in mechanics of materials is assigned to each team. You will develop a tabletop device which can be used in the classroom to enhance learning. These tabletop experiments and demonstrations will be kept as teaching devices for use by instructors who teach Mechanics of Materials EMA 303/304.

Use your creative ability. Consider specific concepts that you struggled with the first time you saw them. Think about what would have enhanced your learning of a topic.

Requirements

This design project will involve

- the development and construction of a tabletop experiment or demonstration suitable for instruction in mechanics of materials,
- a written report including instructions for use and descriptions for suggested demonstrations and experiments,
- a thorough mechanics analysis of the device constructed, and
- a budget report of all expenditures.

It is intended that this design project will reinforce introductory topics and develop on the advanced skills being studied in this course.

Budget

Each team will be given a materials and supplies budget of $40 to be used in the Mechanical Engineering Stock Room. Team members will perform necessary machining tasks with the assistance of Rick Williams in the Mechanical Engineering Student Shop.

Some limited additional funds are available for expenditures over the budget amount with the instructor's prior approval.

Figure 1. Design assignment used in the Advanced Mechanics of Materials class.

Each team was given a materials and supplies budget of $40 to be used in the "Hardware Store" of the College of Engineering Central Service Shops. Team members performed their own machining in the Mechanical Engineering Student Shop. The majority of the teams only spent a fraction of their budget and the remaining funds were used to supplement and enhance the projects.

II. Tabletop Demonstrations and Classroom Experiments

Six of the nine projects completed by the Advanced Mechanics of Material class were developed into teaching tools for use in Mechanics of Materials and added to existing demonstration devices commonly used by the instructors for this course and a course in Statics and Mechanics of Materials. The new devices were designed to demonstrate concepts such as: axial loading, temperature effect, stress concentration, elastoplastic bending, buckling, creep and fatigue. Three of these devices and the associated demonstrations are discussed below.

<u>Temperature Effect Demonstration:</u>

The temperature effects apparatus includes a thermostat containing a coiled bimetallic strip mounted on a stand, 9 V battery, ruler, hair dryer, and thermometer. The manufacturer of the thermostat was contacted by the design team to determine that the bimettalic strip was made of Invar (35%Ni 64% Fe) with a coefficient of thermal expansion of 2 μ in./°C and a MnCuNi alloy ((72% Mn 18% Cu 10% Ni) with a coefficient of thermal expansion of 20.5 μ in./°C. This demonstration is most effective if a live image of the coil can be projected on a screen using multimedia equipment available in some modern classrooms. If this is not available, still shots like those shown in Figure 1 can be used. Because the bimetallic coil cools quickly, it is also feasible for groups of students to conduct their own hands-on experiment.

When this demonstration is employed in the Mechanics of Materials class to explore the concept of temperature effects, the instructor first asks the students to consider a straight bimetallic strip. If the materials are made of Invar and the MnCuNi alloy described above, the coefficients of thermal expansion differ by a factor of 10. A change in temperature of 1 °C would cause the MnCuNi to lengthen by 20.5 μ in. while the Invar only increases in length by 2 μ in.[1] Students are asked to determine which way the strip will bend.

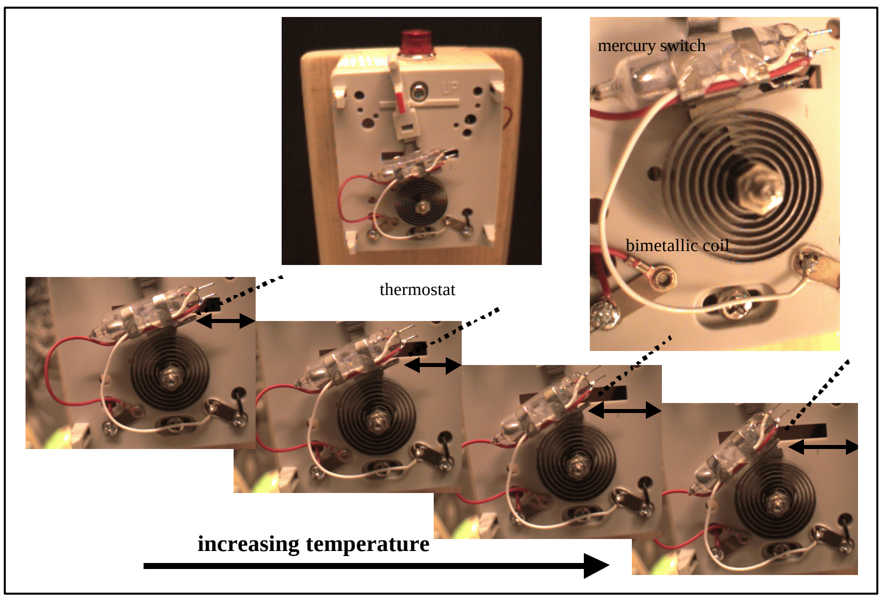


Figure 2. The temperature effects apparatus is shown in the various images. The series of images at the bottom of the figure are taken as the bimetallic coil was heated with a hair dryer.

After this thought experiment, the bimetallic coil in the thermostat shown in Figure 2 is considered. Movement of the bimetallic coil can be measured from either the distance between the tip and a fixed point (shown with a double ended arrow) or the change in angle of the straight portion at the end of the coil (dashed line). Students observe that when heat is applied to the coil, the coil opens up. Using this information and the thought experiment discussed above, they are asked to determine which side of the metal in the coil is Invar and whether the Invar is in tension or compression.

The students are asked to confer with a neighbor in both the thought experiment and the analysis of the demonstration prior to the class discussion. This gives students ample time to think through the problem and more confidence of their answer, which increases overall participation in the class discussion. The majority of the students determine correctly that the Invar is on the outside of the coil.

This demonstration can also be used as the basis for an example problem when advanced topics of stresses in beams is addressed.[2]

Stress Concentration Demonstration:

The stress concentration apparatus includes a latex sheet with a circular hole in the center attached to a wood frame. Ruled lines are drawn on the latex prior to loading and a small ruler is used to measure the distance between these lines before and after loading is conducted.

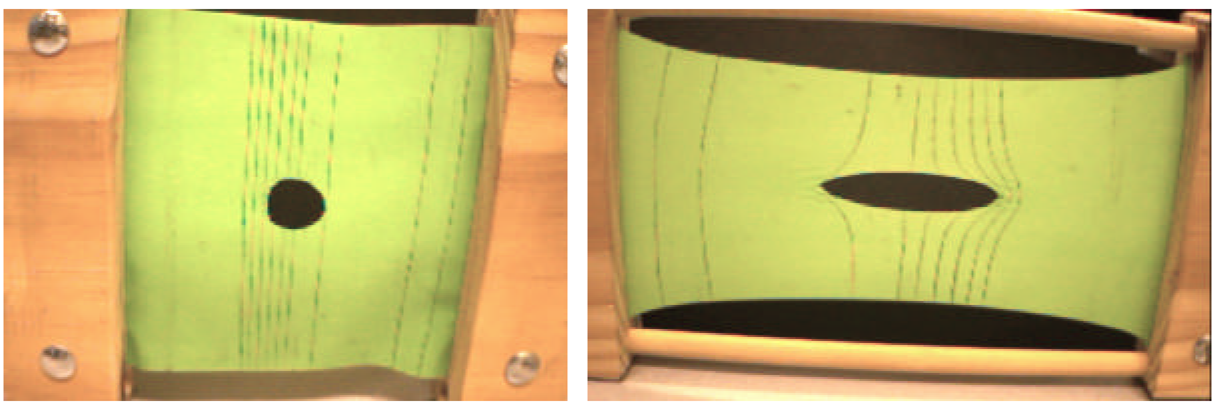


Figure 3. The stress concentration apparatus is shown before and after deformation.

Prior to the demonstration, students in the Mechanics of Materials course are reminded that if we stretch an idealized uniform sheet we find that the stresses and strains that develop at an arbitrary cross section are uniform. The demonstration helps to illustrate that when an abrupt change in geometry is introduced, higher nonuniform stresses and strains are produced near a hole or notch.[3] The latex sheet used in this demonstration allows us to dramatically stretch a hole to see how it deforms as shown by Figure 3.

Originally the parallel lines on the latex sheet are 3.5 mm apart. If the sheet is uniform, we would expect the lines to spread apart uniformly when the sheet is stretched. In the sheet containing a hole, the lines are no longer uniformly spaced when the sheet is stretched. The distance between the lines can be measured by the students at the far edges of the sheet and at hole. The sturdy wood frame allows this demonstration to be passed around the class so that several students can make measurements. Students can also touch the latex sheet and keen observers note that the tension in the sheet is higher near the hole than near the edge of the sheet.

An estimate of the strain near the hole (where the lines are now ~15 mm apart) and the strain near the edge of the sheet (where the lines are now ~7 mm apart) can now be calculated using:

$$e = \frac{L_f - L_i}{L_i}$$

Students are than asked to work with a partner to determine how this information can be used to estimate the stress concentration produced by the hole. The majority of the students come up with the expression:

$$K = \frac{s_{\text{maximum}}}{s_{\text{nominal}}} \approx \frac{s_{\text{hole}}}{s_{\text{edge}}}$$

And several groups will have calculated that the stress concentration factor is approximately 3.5, by assuming elastic deformation and realizing that the expression $s = Ee$ can be where E cancels out of the expression above. This value can be compared to tabulated stress concentration factors for flat bars with circular holes. The dimensions of this undeformed sheet with a hole give a value of 2.6 for the stress concentration factor.[4] The students are asked to speculate on the discrepancy between their calculated value and tabulated value. One source of error that the students can easily note is that the thin latex sheet cannot support compressive stresses thus some out of plane buckling is observed at the far edges of the elongated hole.

To illustrate why the concept of stress concentration is important, several small latex samples with the same nominal cross section can be distributed to the students for a hands-on experiment. (With a larger class size a few volunteer experimenters can be called upon.) Students are asked to break the various sheets containing holes and notches as well as a uniform sheet. The students easily determine that significantly less force is required to break the latex containing a stress concentration than it takes to break the uniform sheet.

Elastoplastic Bending Demonstration:

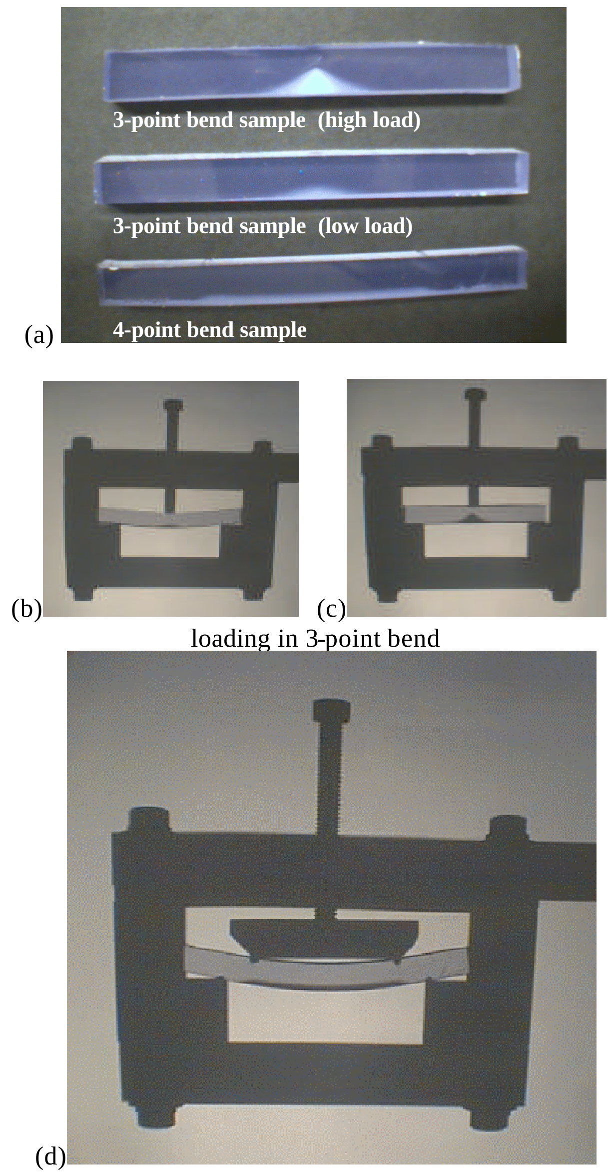
The elastoplastic bending apparatus includes a metal frame with adjustable loading points, Lexan beams, a wrench, and an overhead projector. (Note: It is desirable to attach rubber pads to the apparatus so that the projector is not scratched and the apparatus remains stationary during loading.) Although the same apparatus can be used to demonstrate stresses in beams loaded in bending using the photoelastic effect, this demonstration takes advantage of permanent changes in the opacity of the Lexan when nonrecoverable deformation is induced.

Many polymers, including Lexan, become optically opaque when they are permanently deformed due to an effect called "crazing."[5] When glassy polymers are deformed in tension, fine lines or fibrils form with an orientation perpendicular to the direction of tensile stress. The opacity or cloudiness that develops is a result of voids that are interspersed inside the polymer fibrils. This effect can be used to observe permanent or plastic deformation due to excessive tensile stress as demonstrated by Figure 4a.

When this demonstration is employed in the Mechanics of Materials class to explore the concept of elastoplastic bending [6], a beam of Lexan is loaded in 3-point bending. Students are asked to predict when they expect crazing to occur first (i.e at the location of maximum normal stress) and at what location on the beam they anticipate seeing the cloudiness develop (i.e. bottom center). They are also asked to confer with their neighbor and make a sketch of how they think the crazing will spread when additional load is applied beyond the elastic limit. The experiment shown in Figures 4b and 4c is then conducted with the apparatus placed on the overhead projector so that the class can see where the cloudiness first appears and how it spreads in a triangular pattern with further loading. Because students' intuition on the topic of maximum stresses in bending is usually underdeveloped, their predictions are often inaccurate and it is usually necessary to spend some additional lecture time discussing these results. It is also important to reiterate at this point that only tensile stresses are inducing the crazing behavior. This can be facilitated by asking the students if they expect the triangle of crazing to spread through the entire height of the beam with further loading. Once the class has come to a consensus on how the crazing will spread, further loading can be conducted to expand the region of permanent deformation.

A follow-up experiment can also be conducted in 4-point bending (Figure 4d). Students should be coached to a draw bending moment diagram before trying to make their predictions for this experiment.

Because Lexan is a birefringent polymeric material, additional experiments can be conducted with this basic apparatus. The device can be modified to support both cantilever beams and simply supported beams so that concepts involving stress distribution and maximum stresses in bending [7] can be easily illustrated. Samples with notches and holes can be produced to explore stress concentration effects [8]. Additionally, the Stress Optic Law [9] can also be introduced as an application of principal stresses [7].



(a)

(b) (c)

loading in 3-point bend

(d)

loading in 4-point bend

Figure 4. (a) Samples showing crazing. (b-d) Overhead projector images of the elastoplastic bending apparatus during loading.

III. Conclusions

The majority of the tabletop experiments and demonstrations developed by the students in the Advanced Mechanics of Materials course have become valuable teaching aids for

Mechanics of Materials and two other associated courses. Additional experiments and example problems associated with these projects have been created each subsequent semester. These contributions have been made by both the author and her colleagues.

Acknowledgements

The author would like to thank the students of EMA 506 Advanced Mechanics of Materials Fall 2000 for their enthusiasm and creativity concerning the projects. The author would also like to thank Rick Williams in the College of Engineering Student Shop for assisting the students with their projects. Funds for this project were provided by the College of Engineering at the University of Wisconsin - Madison.

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