AC 2010-925: A SELF-DESIGNED EXPERIMENT FOR AN UNDERGRADUATE MATERIALS SCIENCE COURSE

Hui Shen, Ohio Northern University

Dr. Shen is an assistant professor at Ohio Northern University. She has taught Materials Science course for Mechanical Engineering students for three years. She also taught Statics, Dynamics, and other engineering courses.

A Self-Designed Experiment for an Undergraduate Materials Science Course

Abstract

At the author's institution, all second-year mechanical and civil engineering students are required to take a materials science course. The course includes a laboratory component to help students gain hands-on experiences in materials testing. In traditional experiments, students are provided with detailed instructions for completing the procedure, use equipment that has already been set up, and perform tests on samples that have already been prepared. This paper describes a self-designed experiment in which students handle almost everything on their own, including material selection, sample preparation, procedure design, test setup, data collection, and result analysis. Prior to undertaking the self-designed experiment, students have finished several regular experiments such as material microstructure observation, Charpy test and tensile test. As a result, students have gained sufficient materials testing skills and background knowledge to conduct their own experiments. At the end of the course, students are required to: 1) write a proposal including objectives and procedures; 2) perform material tests; 3) write a report; and 4) present their work in class. This process has been conducted for the last two years. Student feedback indicates that overall students enjoy the experience and believe it should be continued for future students. This self-designed experiment increases students' interests in materials science and engineering study, and also improves engineering problem solving skills which are crucial to enhancing undergraduate engineering education.

Introduction

This paper discusses a second-year materials science course required for all mechanical and civil engineering students at the author's institution. This course introduces fundamental physical and microstructural characteristics of materials and discusses how these relate to their mechanical behavior. It includes a laboratory component to help the students gain hands-on experiences in materials testing. In traditional experiments, students simply follow the instructions provided by a lab instructor, use equipment that has already been set up, test samples that have already been prepared, and obtain results that are expected by the instructor. In this way, students complete the test relatively passively. The primary benefit of this approach is that it provides the students with exposure to a wide range of experimental techniques efficiently. Even so, the number of experiments that can be accomplished is limited by both time and equipment. The end result is that while students do gain hands-on experience and a passing familiarity with several experimental techniques, there is no opportunity for deeper learning, or for the application of theory that is one of the claimed objectives of the laboratory component.

For the past two years, the author has concluded the course with a student-designed experiment in which students complete almost every stage of the process on their own, including material selection, sample preparation, procedure design, test setup, data collection, and result analysis. This self-designed experiment has increased student interest in materials science, improved student problem solving skills, and encouraged independent thinking. In addition, as students present their work in class, this assignment also allows students to practice their communication skills. Students are also exposed to a variety of experiments by listening to other presentations.

The author's institution, Ohio Northern University (ONU), is a comprehensive university with colleges of Arts & Sciences, Business, Engineering, Pharmacy, and Law. The college of engineering at ONU, with a student population of approximately 470 undergraduates, offers bachelor degrees in five accredited programs: civil, mechanical, electrical and computer engineering, as well as computer science. The University is currently on a quarter system, with ten-week instructional periods. Materials Science, offered in the spring quarter, is required for all second-year mechanical and civil engineering students. Usually there are two sections with 50-70 students enrolled in the course each year. Prior to enrolling in the course, students will typically have completed five quarters of general engineering, mathematics, and science courses. These include several courses in solid mechanics and one chemistry course. In addition, the required Freshman Engineering course provides an introduction to the machine shop which allows students to prepare samples for materials testing.

Self-designed Experiment Plan

As mentioned previously, the Materials Science course is offered during a 10 week term. A lab schedule is distributed to students on the first day of class. During the first week students receive a lab tour and are instructed in lab safety. During the following six weeks, six traditional experiments are conducted by students, including one material microstructure observation, Charpy, hardness, creep experiment and two tension experiments. Each experiment has a clearly-specified objective and procedures. Students complete each experiment with assistance from a lab instructor. While students are aware of the self-designed experiment from the first day in class, they are required to turn in a proposal for the self-designed experiment at the end of the seventh week. At this point, students have become familiar with material testing techniques and equipment, and have sufficient background knowledge to design their own experiment.

To help students identify potential experiments, the instructor discusses various phenomena with students during lectures. The availability of facilities and materials is also discussed with students. Students have access to existing material supplies and to samples from previous years. They can also ask the instructor to purchase additional materials on a limited basis. Students are required to discuss their ideas with the instructor prior to the submission of the proposal. The instructor then reviews each proposal with the students to resolve any concerns. A time sheet for different equipment is also signed by students to avoid waiting.

According to the schedule for this self-designed experiment, students are required to:

- 1) Submit a proposal in the 7th week on what they intend to do, what materials they want to test, procedures, and expected results;
- 2) Perform material experiment in the 8th and 9th weeks which takes approximately 2-3 hours on average;
- 3) Write a report; and
- 4) Present their work in class in the 10th week. A survey regarding the experiment is conducted during the last class. In the next section, a few self-designed experiments are used as examples to show how the students perform the experiment and what results they obtain.

Experiment Examples

Over the past two years, students have completed a wide variety of self-designed experiments, as illustrated by the following examples. In each case, students designed the procedures, prepared samples, and completed each experiment with minimal guidance from the instructor.

Strengthening by Alloying

Solid-solution strengthening is one of the techniques to strengthen and harden metals¹. High-purity metals are usually soft and weak. Alloying metals with impurity atoms usually increases the tensile and yield strengths. Some student groups were very interested in this mechanism and tested this theory in their self-designed experiments. This experiment is the most popular self-designed experiment so far. Totally about 6 groups performed this type of experiment in the last two years. Students conducted either tensile or hardness tests to study strength or hardness change after alloying. Lead-tin (Pb-Sn) alloy was usually made due to the fact that lead and tin have relatively low melting points compared to other metals and are easy to operate. In this experiment, the following procedures were designed by students:

- Make molds using plaster of Paris
- Heat up oven to a desired temperature
- Put lead and tin in containers with desired amount of materials
- Melt lead and tin and pour the liquid to molds to make test samples of pure lead, pure tin and 50 wt% Pb - 50 wt% Sn alloy
- Test each sample
- Collect and compile test data

Figure 1 shows the molds and test samples that students made for the tensile test. In this experiment, students observed that the Pb-Sn alloy has a higher strength than the pure lead and tin. It should be mentioned that some groups succeeded in the experiments but others did not obtain decent results. For example, one group failed the tensile test because samples they made contained big air bubbles. Students analyzed what caused the failure of the experiment. This is also a good learning experience.

Figure 1: Tensile test samples of lead, tin and the alloy in the molds made from plaster of Paris

Effect of Welding on Structural Metals

The objective of this experiment is to observe the effect of welding on commonly used metals. One group of students used two types of metals: steel and aluminum. They cut steel and aluminum samples in half and used a TIG welder to weld the samples together, then they performed the tensile test on the original and welded samples as shown in Figure 2. Test results show that the welded aluminum samples have lower ultimate strength but welded steel samples have higher ultimate strength than the original samples. Another group did a similar test to compare the influence of MIG and TIG welds on the tensile strength of 4143 steel tubes as shown in Figure 3. They found that that the TIG weld is more desirable for welding 4143 steel tubes.

Figure 2: Unwelded and welded tensile test samples of (a) 6061-T6 aluminum and (b) 1018 steel after tensile test

Figure 3: 4143 steel tubes welded with TIG and MIG welds after tensile test

Temperature effect on properties of materials

Temperature has a great influence on properties of materials¹. In lectures on failure of materials, the Titanic tragedy has been used as one example to show Ductile-to-Brittle Transition

Temperature (DBTT) of metals with BCC (body-centered cubic) crystal structure. Some groups are interested in the DBTT phenomena and test a variety of materials to see the influence of temperature on different materials. One test is to find out how temperature affects the impact strength of 1018 steel. In this experiment, students made Charpy test samples as shown in Figure 4 in the machine shop. Then they cooled some samples with liquid Nitrogen and performed Charpy tests on the cold samples as well as on the samples at room temperature. The results show that the 1018 steel has much lower impact strength at low temperature than at room temperature. Another group did similar tests on brass samples as shown in Figure 5 and did not observe an obvious impact strength change over a large range of temperature. They tried to analyze the sources of errors during their presentation and finally it was pointed out by their classmates that the brass has FCC (face-centered cubic) crystal structure and therefore there is no DBTT for such a metal.

Figure 4: Charpy test samples made from 1018 steel

Figure 5: Brass Charpy test samples after test.

Experiments on wood properties

Two groups performed experiments on woods. One did compression tests on wood samples to see how wood fails with loading directions parallel or perpendicular to grains as shown in Figure 6. Another group of students tested the flexural strength on oak, pine, and balsa woods.

Figure 6: Fractured wood samples after compression test.

Assessment and Discussion

A survey for this self-designed experiment has been conducted during the last two years by the instructor. 108 students of 114 students enrolled in the course submitted their responses. The following questions were asked in the survey:

- 1) What do you like best about this self-designed experiment?
- 2) What do you like least about this self-designed experiment?
- 3) What is the most challenging part in this experiment?
- 4) Do you think we should continue to do this experiment in the next year?
- 5) If your answer for question 4 is “Yes,” what suggestions do you have to improve this experiment for the next year?

While it is not realistic to list all the responses from the 108 students in this paper, only significant responses are showed in the Appendix and are summarized as follows. For question 1, students like best:

- The freedom of doing the experiment: “The freedom to do the test we wanted to do. It satisfied my curiosity.” (84 responses)
- To complete almost every stage of the process on their own: “I liked it because we were able to do everything. We had to do the setup and everything as opposed to some other labs.” (11 responses)
- To learn more knowledge: “This lab allows us to learn more about what we find interesting. We learn more from labs that we designed ourselves.” (8 responses)
- Equipment: “Experience in using the equipment.” (6 responses)

From the responses listed above, it seems that students enjoyed the freedom of the experiment. This experiment gave them a chance to apply the knowledge they learned in class. Materials Science is a type of course in which many theories, such as “Strengthening by Alloying”, come from or can be tested by experiments. Learning various theories in class may create additional curiosity in the students. Just as one student stated, “This experiment gave us a chance to further investigate something we found interesting in class.” This experiment also gave students a chance to practice on many aspects of an experiment including procedure design and sample preparation. Students also gained knowledge from experiments conducted by other groups.

While question 2 is what students like least about this experiment, they do not like:

- Formal Report: “The required lab report” (28 responses)
- Presentation: “The presentation. But I see its value.” (17 responses)
- Operation of machines: “The tensile machine broke and was kind of a pain.” (11 responses)
- Timing: “I don’t like that it is during the busiest time of the quarter making it hard to do a more in depth study.” (9 responses)
- Limited options of materials and equipment: “Not enough variety of materials to test.” (8 responses)
- Long experiment time. “As cool/interesting as it is to get to make alloy samples, it is time consuming which takes away from more of the learning about the properties.” (6 responses)
- Uncertainty of the result: “That there was a type of unknowing, like you weren’t sure if you were doing it right.” (4 responses)
- Making the samples: “Making the samples.” (3 responses)
- Procedure design: “Find the procedure on our own. It was however necessary.” (3 responses)

It seems that students thought the report and presentation were time consuming and did not like to spend time on them. While writing the report is an essential skill for engineering students, giving the presentation is not only a practice for communication but also to show their ideas to other students and to let other students learn things from their experience. Some students complained about the limited variety of materials to test, and others complained about the lab equipment. Bad things happen sometimes in the real world. They might learn from this experience that sometimes they have to prepare for the worst case and do more background research to avoid it. The problem for scheduling the self-designed experiment will be discussed later in this section.

For the third question (“what is the most challenging part in this experiment”), significant responses are summarized as follows:

- Coming up with a topic: “Coming up with an idea that sounded different/interesting” (36 responses)
- Some specific procedures in the experiment: “Trying to cool and heat our samples were probably the most challenging parts.” or “Making samples to test.” (31 responses)
- Timing: “Organizing everything and staying on time so that you can get it done by week 10. It was also challenging doing things we have never done before (making molds).” (12 responses)
- Report: “It will probably be writing the final report.” (7 responses)
- Presentation: “Decide how to present what we did.” (4 responses)

From the above comments, it can be observed that students felt it was challenging to come up with an idea, to make samples and to figure out how to complete the experiment. However, they worked together as a group to solve all the problems mostly on their own. This is a good practice for engineering students.

For question 4 (“Do you think we should continue to do this experiment in the next year?”), 106 out of 108 students (98%) answered “Yes.” Comments are listed in the Appendix. Two students said “No” to this question. One student did not comment and another student commented: “It was too time consuming.” It seems that overall students enjoy the experience and believe it should be continued for future students.

For question 5, students suggested to improve the experiment in the following ways:

- Example ideas: “Maybe next year, you could give a sheet with 10-20 ideas for people to pick from” or “Give more examples of possible tests.” (17 responses)
- Timing: “Start this lab before finishing with other labs” (11 responses)
- Materials: “Have a larger variety of material samples that can be used in testing.” (10 responses)
- Presentation: “Make the presentation more formal.” (5 responses)
- Equipment: “Maybe not for next year, but eventually, purchase a larger, more efficient oven” (4 responses)
- Equipment operation: “More instructions on the use of the different machines.” (3 responses)

Based on the above suggestions, some modifications will be made to improve the self-designed experiment. First, detailed rubrics for presentation will be used as guidelines and grading rules for the presentation. Second, more potential materials will be purchased to make sure that students have more options in materials for testing. Third, move the due date of the proposal forward by one week. Finally, show students a list of ideas for potential experiments.

Conclusion

This paper describes a self-designed experiment conducted in a Materials Science course. Students develop and conduct the experiment on their own, including procedure design, materials selection, sample preparation, machine operation, data collection, and result analysis. They also need to do an oral presentation in class and write a formal report. Based on the students’ feedback, the author believes the self-designed experiment was a success, and provided a meaningful and enjoyable education experience for those students enrolled in the course.

Acknowledgments

The authors acknowledge the financial support of the National Science Foundation through grant number DMR- 0423914 as well as the help and support from Mr. William Kanzig.

Bibliography

[1] William D. Callister, Jr. and David G. Rethwisch, 2008, Fundamentals of Materials Science and Engineering – An Integrated Approach, 3rd Edition, John Wiley & Sons.

Appendix

While it is not realistic to list all the responses from the 108 students in this section, only significant responses for each question are showed here.

1) What do you like best about this self-designed experiment?

- “The best part about this lab was that, as the title says, we got to design it ourselves. This was great because we then had a chance to further investigate something we found interesting in class.”
- “I liked it because we were able to do everything. We had to do the setup and everything as opposed to some other labs.”
- “The fact that we could do a lab that interested us the most.”
- “It was an interesting lab, which no one has ever done. This made it every interesting when we found the results.”
- “I like that we were allowed to use anything in the lab.”
- “Choosing to work on what we were most interested in.”
- “It was interesting to be able to choose what to do. There are so many different things that would have been fun.”
- “The flexibility of the lab and being able to do whatever we wanted was great. It was also nice to be able to work independently as a group conducting the experiment on our own time.”
- “I liked that we are already familiar with all the lab equipment, so we could choose a lab we liked the best.”
- “We were able to learn something new and interesting.”
- “Being able to be creative and do what we wanted to do.”
- “The responsibility of having to do a lab on our own, instead of just following instructions. Felt I better understood”
- “I liked seeing what ideas other people used for this.”
- “It was fun to do something creative and on my own. I also liked that I could do it within a fairly large range of time.”
- “It gives each student a chance to explore something that they find interesting about this course.”
- “The freedom to do the test we wanted to do. It satisfied my curiosity.”
- “This lab allows us to learn more about what we find interesting. We learn more from labs that we designed ourselves.”
- “I liked that we were able to select our own project based on things that interested us, and also that we had to figure out our own procedures which allowed us to really learn what I was doing.”
- “I liked the idea of planning our own lab and figuring out how to properly create samples and perform the experiment.”
- “I like how we had to be responsible and complete a lab on our own.”
- “Experience in using the equipment.”
- Etc.

2) What do you like least about this self-designed experiment?

- “Formal report”
- “Lab report. Although I think it is necessary.”
- “The required lab report”
- “Presenting but I never did like presenting things. So it was good for me.”
- “The presentation. But I see its value.”
- “I don’t think a presentation is necessary considering we’ve all done the labs thus far.”
- “Give us some directions as to what you want in terms of presentation.”
- “Not enough time”
- “As cool/interesting as it is to get to make like alloy samples, it is time consuming which takes away from more of the learning about the properties.”
- “There was a lot of extra work especially when it is the end of the quarter and we all have a lot to do.”
- “Find the procedures on our own. It was however necessary”
- “The waiting time for things like the oven is very long.”
- “The tensile machine broke and was kind of a pain.”
- “Making the sample was difficult.”
- “Couldn’t do the exact lab we want to do.”
- “Not enough variety of materials to test.”
- “The really old computer and printer connected to the Instron.”
- “There was no way that we knew of to compare to theoretical results, so no way of knowing how right we were.”
- “Limited resources.”
- “It took much longer than all of our other labs did.”
- “That there was a type of unknowing, like you weren’t sure if you were doing it right.”
- “There were no many samples to choose from in the Material Science lab.”
- “The fact that everyone was using the lab at the same time and it was kind of hard to get things done.”
- Etc.

3) What is the most challenging part in this experiment?

- “Actually deciding what type of test to perform and to find the material for the test.”
- “Coming up with an idea.”
- “Coming up with something practical and doable.”
- “Coming up with a unique idea.”
- “Finding good samples to test.”
- “Making consistent samples.”
- “Creating our own samples.”
- “Getting the materials needed.”
- “Working with plaster of Paris to make the mold.”
- “Creating a sample that is good enough to use, and get decent results.”
- “Learning how to use the equipment.”
- “Interpreting our data since it was so skewed from our expected results.”
- “Having enough knowledge about each concept to be able to draw conclusion from the tests. This did help to understand material better.”

- “Getting our test data values close to our expected values.”
- “Analyzing the results and determining if they are valuable.”
- “Deciding how to present what we did.”
- “Create a lab with correct procedure to get expected results.”
- “Make sure all the information was correctly presented in the report and presentation was a little challenging.”
- “Unexpected challenges.”
- “Making sure everything will work.”
- “Just making sure the procedure is correct.”
- “Setting it up to work exactly how you want it.”
- “Having to figure out how to do everything.”
- “Getting good results.”
- Etc.

4) Do you think we should continue to do this experiment in the next year?

For this question, 106 out of 108 students think this experiment should be continued in the following years. Students who said “Yes” commented:

- “I think this is a good idea.”
- “It was really cool being able to choose and design our own lab.”
- “It is fun and makes me feel like an engineer.”
- “It is great to see all of the different information.”
- “Good learning experience.”
- “The lab forces us to learn more/put forth more effort.”
- “Keep everything the way it is.”
- “I enjoy doing the lab.”
- “It is very helpful to develop skills of being able to design and perform a lab essentially on your own.”
- “This was a good lab because we took part in all areas including designing the lab, making the samples, interpreting the results and presenting them.”
- “The lab was a good way to experiment and support the topics that are taught in class.”
- “Despite problems, it is necessary.”
- “I think that self-designed labs are helpful in learning, independent thinking and planning.
- “Brings a lot of what we have learned together.”
- “I thought that it was a very good and original learning experience.”
- “Keep everything the way it is.”
- “Our group learned a lot from doing the research and hands on part of the lab.”
- “I really enjoyed it and feel it is a great learning tool.”
- “Very helpful.”
- “It is very helpful to develop skills of being able to design and perform a lab essentially on your own.”
- Etc.

Two students said “No” to this question. One student did not comment and another student commented:

- “It was too time consuming.”

5) If your answer for question 4 is “Yes”, what suggestions do you have to improve this experiment for the next year?

- “Give more details about what you want for the presentation.”
- “More samples, more organized way of storing samples.”
- “More options of materials to test,”
- “Remove presentation.”
- “Set more guidelines to make sure proper machinery is available, and give more examples of possible lab ideas.”
- “Help students find real world applications for the results.”
- “Move it forward by a week.”
- “Have the proposal due earlier in the quarter.”
- “Give it to the students earlier in the year so they could possibly go more into detail about their lab.”
- “I didn’t really like to have 2 or more similar labs in one class, so maybe limit how many people can do which lab.”
- “Maybe purchase a larger, more efficient oven.”
- “Give an example of a full designed lab.”
- “Maybe a little more direction.”
- “A list of potential experiments might be helpful.”
- “I think every group should be required to make their samples.”
- “Make the presentation a formal presentation.”
- “Make signed up lab times definite and do not allow other students to use the lab on unassigned times. This happened to us and led to our waiting time coming out to an hour.”
- “I wouldn’t change anything.”
- “Not any suggestions are needed. Plenty of time was given to do the lab and things went very well.”
- “I think this year was fine.”
- “None, lab was fine.”
- Etc.