Integrating Experimental Studies into a Senior Level Course: Smart Materials and Structures

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Abstract

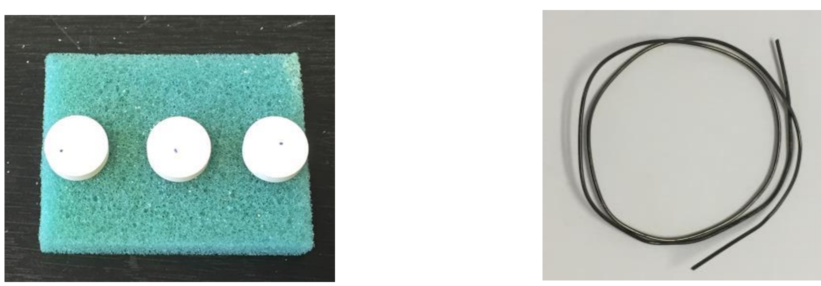
Smart Materials and Structures is a senior level technical elective course for undergraduates in which three types of smart materials are introduced, including piezoelectric materials, shape memory alloys, and magnetostrictive materials. The involved techniques to study these materials are pioneer in the field of materials science and engineering and most of them are still in the research stage. For most students, realizing these advanced materials and technology is their first time. Therefore, it is a challenge to for students to understand the course material in depth. In order to overcome this challenge, experimental studies are introduced as part of the course through an active learning platform. Overall, four labs are designed and conducted to investigate the properties and performance of piezoelectric materials and shape memory alloys. The outcome of the experimental studies is evaluated by written reports consisting of learning objectives, experimental methods, results, and discussions. These lab sessions significantly enrich the course material and provide students an active learning environment where they can apply the fundamental principles for problem solving while interacting with other students and instructors. The students also gain hands-on experience in the process of preparation and operation of these labs. The impact of experimental studies on student learning outcomes is assessed based on the lab reports and anonymous questionnaires. The results indicate that this approach is effective for enhancing the students' motivation, understanding of the course materials, and learning outcome.

1. Introduction

Smart Materials and Structures is a senior level technical elective course in which three kinds of smart materials are introduced, including piezoelectric materials, shape memory alloys, and magnetostrictive materials. Additionally, adaptive structures and active vibration control systems are also covered in the course. These smart materials listed above can respond under external loadings such as electric fields, temperature changes, and magnetic fields, thus making them excellent candidates to be served as sensors, actuators, and transducers for the applications in many fields such as energy harvesting, structural health monitoring, and medical devices [1-4]. The involved techniques in studying these smart materials are pioneer in the field of materials science and engineering and most of them are still in the research stage. For most undergraduate students, this is their first time to recognize these advanced materials and technologies. Therefore, it is a challenge to help students to understand their unique properties and performance in depth. In order to overcome this challenge, four experimental studies are designed and conducted throughout this class. The goal is to improve the learning effectiveness by linking the experiments and theoretical principles of the materials and engaging students through active learning. The outcome of these laboratory studies is evaluated and the results suggestion that integration of experiments into the course is effective to improve the students' learning and motivation.

2. Experimental methods

Four experiments are integrated into the course to study the properties and performance of piezoelectric materials and shape memory alloys. Magnetostrictive materials are not included due to the limitations of our lab facility. The first three experiments are devoted to investigating the piezoelectric material because it has been extensively studied experimentally and theoretically and thus its properties are well understood. A type of piezoelectric material, lead zirconate titanate (PZT) as shown in Figure 1(a), is chosen to be used in our experiments because of its strong piezoelectric effect and low cost. PZTs exhibit a unique electromechanical coupling behavior. In other words, PZTs can induce electrical output when subjected to mechanical loading; whereas, they can produce deformation under an electrical field. The last experiment is conducted to demonstrate the behavior of shape memory alloys. A nitinol as shown in Figure 1(b), an alloy of Ni and Ti, is used in the lab since it is the most well known shape memory alloy that was developed by the U.S. Naval Ordance Laboratory.



(a) (b)

Figure 1. Photographs of (a) PZT specimens and (b) a nitinol wire

The first two experiments, including measurement of electric displacement vs. electric field loop of PZTs and determination of electromechanical behavior of PZTs through compressive tests, are designed to cover the fundamental concepts that emphasize on piezoelectric and mechanical properties. Figure 2 shows the needed equipment for the first experiment (measurement of electric displacement vs. electric field loop) including a high voltage amplifier, a function generator, a data acquisition system, a breadboard, a capacitor, and wires. A MTS system used for the second experiment (determination of electromechanical behavior) is shown in Figure 3(a) and Figure 3(b) represents a PZT specimen during a compressive test. These two labs involve circuit buildup and electronic instrument operation, which allows students apply their knowledge learned in the course of circuit. Each group of four students is required to conduct the tests independently throughout the entire process including specimen preparation, circuit integration, and equipment operation. Finally, students are required to perform data analysis and result discussions. From the results, students need to identify some properties including piezoelectric coefficient, coercive field, remanent polarization, saturation of polarization, and elastic modulus, which can help them understand the applications of the piezoelectric material. For instance, PZTs have been used for memories owing to their remanent polarization that keeps “memories” even though no external field is applied. Additionally, the second experiment demonstrates the ability of sensing for the piezoelectric material under dynamic compressive loads. In these two labs, two types of PZT specimens are tested so that students can realize their behavior difference due to their different structures. This can reinforce a key concept in material science and engineering: structures alter properties of materials.

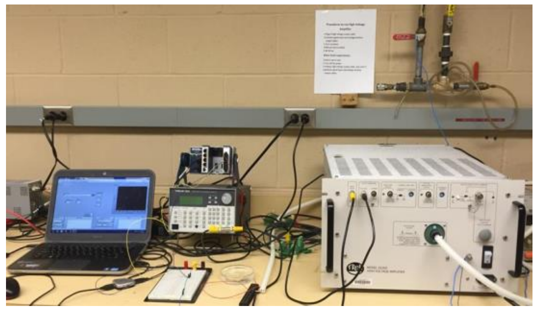
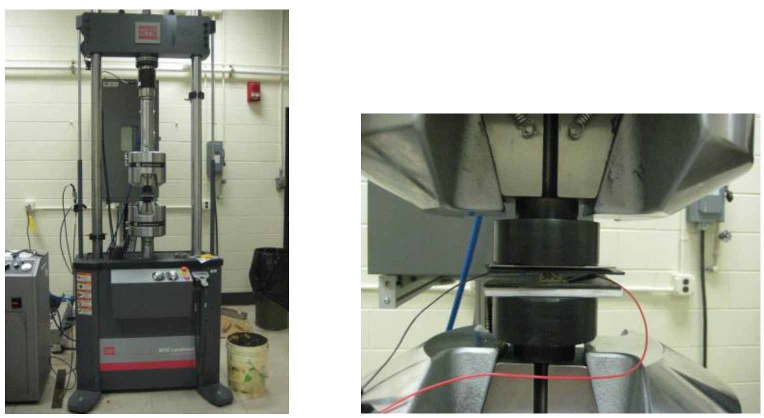


Figure 2. Photographs of the needed equipment for measurement of electric displacement vs. electric field loop of PZTs



(a) (b)

Figure 3. (a) MTS test system for determination of electromechanical behavior of PZTs and (b) a PZT specimen during compressive test

The third experiment is to build piezoelectric generators and actuators. The main purpose of this lab is to determine the PZTs capacity of energy harvesting and actuating. Student groups are given needed materials and supplies. For the piezoelectric generator, they are asked to build up a circuit with incorporation of PZT elements and then demonstrate that the device built can light up a LED. For the piezoelectric actuator, students are required to assemble the experimental setup and show the ability of PZTs to actuate a cantilever beam. Finally, students need to complete analysis questions such as calculation of energy used to power the LED, calculation of energy stored in the capacitor, estimation of the time needed to charge a battery using their device, etc. Additionally, they are required to provide suggestions for improving their device setups.

The fourth experiment is performed to study the shape memory effect of shape memory alloys. First, a nitinol wire is bent in various shapes and then placed in hot water. Students can observe the effects of temperature change on the wire. Second, students learn to set up the original shapes of the wire by heating it above austenitic transition temperature. From the results, student can identify the transition temperature of the nitinoal wire and understand its austenitic-martensitic phase transform due to the temperature change, thus producing the shape memory effect. Students are also required to find a few application examples in which the shape memory alloys can be used after the lab.

3. Assessment

The outcome of assessment is evaluated by written reports. For each lab, students are required to complete a report which includes learning objective, experimental methods and procedures, results, and discussions. In their written reports, most students demonstrate their good ability to apply fundamental principles into the experimental studies, understand the aspects of the materials, and recognize the applications of the materials in engineering fields. At the end of the semester of Fall 2017, a questionnaire was handed out in class to assess the learning effectiveness. Four questions related to the experimental studies are:

1. Do you agree that the lab is a good way to learn and reinforce the fundamental concepts of the materials?
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree

2. Which of the following has been the best source(s) for you to learn the course materials?
   a. Lectures
   b. Homework
   c. Labs
   d. Midterm exam
   e. Examples

3. Which of following has been the most useful in helping with self-evaluation of your performance in the course?
   a. Homework
   b. Labs
   c. Midterm exam

4. What do you like and dislike about the lab?

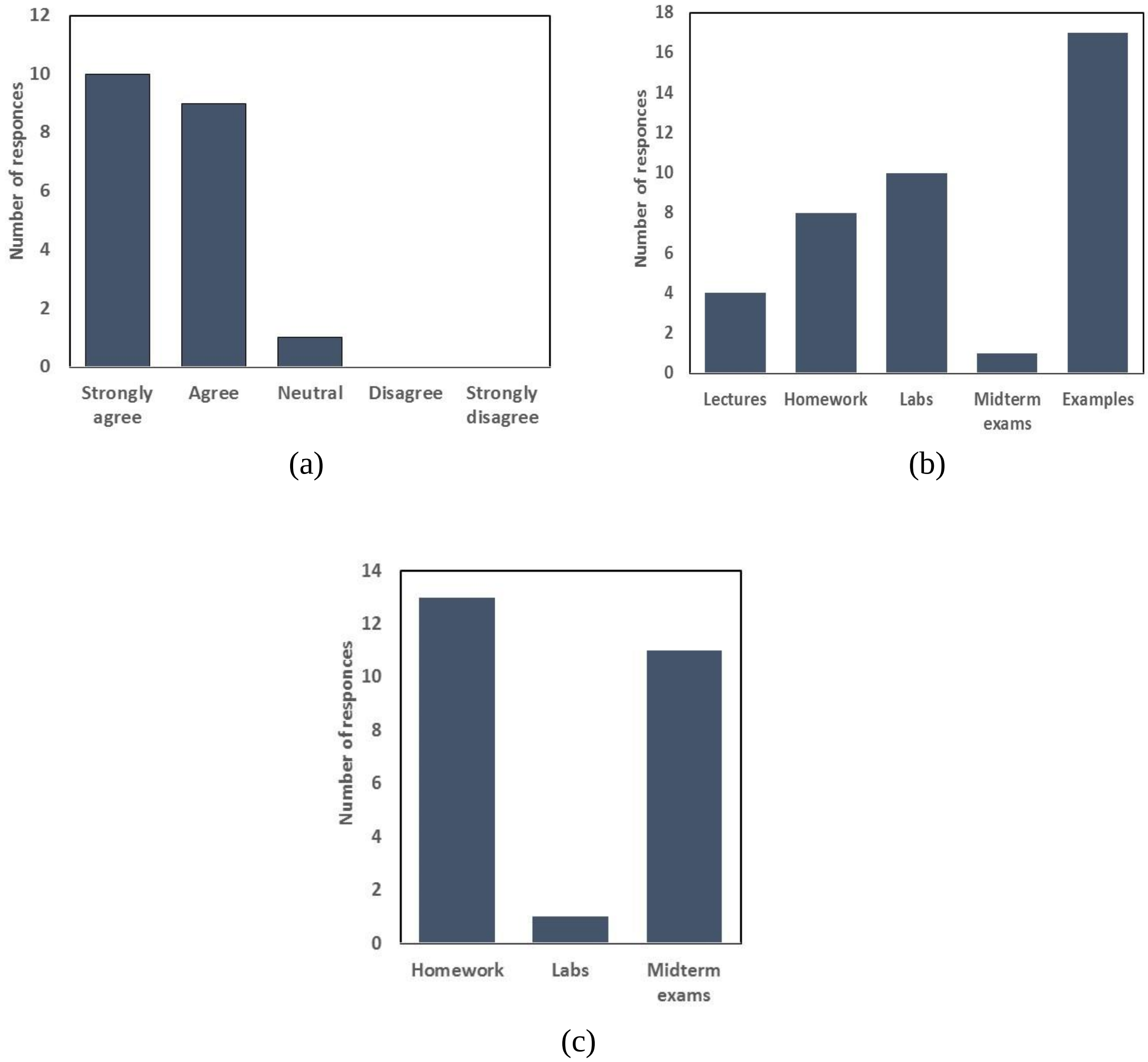


Figure 4. Distribution of the number of student responses to (a) question1, (b) question 2, and (c) question 3 in the survey questionnaire. The survey was done in the Fall 2017 class.

Figure 4 presents the results of student responses to the first three questions, respectively. As shown in Figure 4(a), the majority of students (95%) agrees or strongly agrees that the lab is a good way to learn and reinforce the fundamental concepts of the materials. Only 5% of students choose neutral and none disagree or strongly disagree. For the second question shown in Figure 4(b), 50% of the students select labs are the best source(s) to learn the course materials, which is lower examples (85%) and greater than lectures (20%), homework (40%), and midterm exams (5%). However, Figure 4(c) shows that only 5% of students agree that labs are the most useful in helping with self-evaluation of their performance in the course. Most students believe that homework (68%) and midterm exams (58%) provide them better evaluation in the class. In response to the open question 4, 79% of students said that they like the interactive, hand-on labs where they were able to be involved. 21% of students complained that the specimens did not work sometime and their group partners did not contribute evenly. In summary, the survey results suggest the experimental studies are favorited by the students and effective for learning the course materials. For their performance evaluation in the class, the students still prefer the traditional ways including homework and exams.

4. Conclusion

In this paper, we reported the integration of four experimental studies into the course of Smart Materials and Structures. The experiments covered piezoelectric materials and shape memory alloys, which focus on the fundamental properties and some applications of the materials. These experiments not only substantially enriched the course materials, but also provided an active learning environment that allows student link the theoretical principles learned in the lectures with the hand-on tests. From the feedback from the students, the experimental studies enhanced their understanding of the course materials and the experiments were one of the best resources for improving the learning effectiveness. In the meantime, the students still value their learning through homework, lectures, examples, and exams. Our results suggest that the implementation of both experimental studies and traditional means is the best way to reach our learning objectives.

References

[1] D. J. Leo, Engineering analysis of smart materials systems, *John Wiley & Sons, Inc*. 2007

[2] C. S. Lynch, The effect of uniaxial stress on the electro-mechanical response of 8/65/35 PLZT, *Acta Materialia*, 44, 4137-4148, 1996

[3] P. Zhao, J. Li, Orientation dependence on electromechanical coupling behavior of ferroelectrics under compression, *Journal of Applied Physics*, 103, 104104, 2008

[4] J. M. Jani, M. Leary, A. Subic, M. A. Gibson, A review of shape memory alloy research, applications and opportunities, *Materials and Design*, 56, 1078-1113, 2014