Presenting a more efficient approach to teach Materials Science

Monika Bubacz and Luiz Dos Reis
The Citadel, Charleston, SC

Abstract

Many students struggle with theory because they cannot always associate concepts from the text to the physical world. This is especially applicable in case of materials science that requires a review of many chemistry lessons and discusses phenomena occurring in a micro-scale world. Moreover, materials science laboratories do not always provide enough hands-on experience for students as not every school can afford a few sets of apparatus stations. The equipment is expensive and some processes are time and energy consuming. The materials science instructor at The Citadel took the more challenging approach in order to enhance student learning. The instructor held small weekly laboratory projects starting at the beginning of the semester that involved heat treatment and analysis of different steel microstructures. The previous course offering had only one project scheduled near the end of the semester. The paper will discuss the laboratory projects in detail and will include the assessment from the instructors and students. The course is offered in the fall to day and night students.

Keywords

Materials science course, metal heat treatment, mechanical engineering laboratory

Materials Science Course at The Citadel

The traditional undergraduate mechanical engineering curriculum has a single materials science course integrated into a four-year plan[1]. Such courses are typically intended for sophomore or junior level students who have completed some of the introductory science courses such as physics and chemistry. Many of the Materials textbooks are designed for a student population with some calculus experience ready to enter into a study of abstract concepts such as those underlying engineering materials. That Materials course may have an associated, required laboratory experience.

American universities, in general, are adding more hands-on engineering projects to their curriculum to attract new students. Hands-on projects are motivating and help sustain students' interest in technology and the curriculum to prevent them from switching to other majors[2]. Challenges include delivery to students with limited experimental backgrounds. Successes include improved satisfaction by the students since they actually practice the concepts being taught[1].

Mechanical Engineering students at The Citadel take MECH 304, Engineering Materials with Lab during their junior year. The course explores the relationships between the microscopic structure and macroscopic properties of materials used in engineering applications. Emphasized is an understanding of the fundamental aspects of atomic and microstructural concepts for proper materials selection, effects of processing on material properties, and enhancement of engineering

properties. Materials under study include important metals and alloys as well as key nonmetallic materials such as polymers, ceramics, and composites. Laboratory exercises are integrated throughout the course to provide practical experience in making decisions concerning material composition and processing in order to optimize engineering properties. Experiences from the field are detailed to demonstrate applicability of concepts. Weekly meetings consist of two hours of lecture and two hours of laboratory.

Teaching materials science can often be unimaginative and uneventful for students. They experience a lot of reading, memorization of processes and definitions in class. Many students struggle with theory because they cannot always associate concepts from the text to the physical world. Recent brain scans performed by University of Chicago suggest that students with hands-on experience have a better understanding and score better than those that study texts only[3]. Lecture coupled with some hands-on demonstration is a powerful teaching strategy for engineering students. Students like testing and breaking test specimens[4]. That is why The Citadel is integrating experience with theory in MECH 304. This paper is written after developing a hands-on materials lab that gives engineering students experimental practices that demonstrate the relationship between materials processing and properties, and that develop data collection, organization and reporting skills

Steel Heat Treatment Laboratories

MECH 304 laboratories are divided into two assignments:

- Laboratory 1 – a heat treatment of steel where students are given heat treatment procedure and are asked for impact test and microstructure results – 6 groups of students are given different heat treatment parameters resulting in different microstructures and consecutive weeks as deadlines for short reports.
- Laboratory 2 – a six weeks long project: students are given a specific grade of steel and asked to design a heat treatment for specific properties, to prove them through testing and deliver a long report with procedures, results and conclusions.

This paper describes students' and instructor's experience related to Laboratory 1. The objectives of the lab are to perform heat treatment of steel and examine properties by utilizing impact test and observing microstructure. The students are divided into 6 groups (the number can be adjusted based on course section population) and each group has a week to perform their heat treatment and testing. The following microstructures are tested: raw material (cold rolled bar pre-notched for an impact test), spheroidite, coarse pearlite, fine pearlite, martensite and bainite. The students are introduced to the equipment (ovens, Charpy impact tester, saws, mounting press, polishing stations, etching, microscope) at the beginning of the semester and provided detailed procedures for heat treatment (temperatures and times). At the end of the Lab 1 period, all results are collected in a form of short narrative reports from each group, tabulated and discussed in class. The range in hardness are from very soft to its maximum hardness that the material can acquire.

Instructor's Perspective

The first week of the Lab 1 period was spent on explaining working procedures for ovens, Charpy impact tester, saws, mounting press, polishing stations, etching and microscope. The students were informed about safety procedures (buddy system, required body protection and equipment care), hazardous materials (etchant) and materials disposal. The students were also asked to schedule their time with ovens (preheating and cooling cycle takes many hours and sometimes only one group can work per day) in order for the instructor to be present during the heat treatment and assure safe handling of heated samples. The students were reminded in class about deadlines, questions about the process were answered and experiences were shared during the period of the Lab 1. Collected results, impact energy value and microscope image for all microstructures, were presented and discussed after the topics of Phase Transformations and Processing of Metals were covered in class (around midterm).

Benefits of Lab 1 experience:

1. The students gained experience with materials laboratory equipment that will be necessary for more independent and design-oriented Lab 2.
2. The students were firsthand exposed to heat treatment they might have heard about (quenching, heat treatment of knives, forging of swords …) and showed interest in other heat treatments and understanding their effect on mechanical properties.
3. Students were enthusiastic about working with dangerous equipment: high temperature ovens and pendulum impact tester.
4. The in-lab experience was mentioned many times during lectures related to often confusing topics related to phase diagrams, phase transformations and time-temperature-transition diagrams.

Disadvantages of Lab 1 experience:

1. Some groups were not aware of what other groups were doing.
2. Equipment procedures had to be repeated frequently otherwise some operations were performed incorrectly (sample mounting, polishing) which made students feel that they did not know what to do. Only the original manufacturer procedures were provided.

Improvements suggested:

1. During explanation of operating procedures students need to take notes. Once explained written procedures should be easily available (original manufacturer procedures proved to be too confusing).
2. Students should be updated on progress of all groups so they understand the differences in procedures and learn from others' mistakes and experiences. Short oral group reports should be provided weekly (after the written report is due and submitted).
3. Equipment needs to be checked often for damage and repaired immediately.

Students' Perspective

There were three sections of MECH 304, two of them with 34 day students (30 cadets and 4 veterans) and one with 8 evening students. One of the students was asked to prepare, distribute, collect and analyze a survey related to students' experience in Lab 1. The survey consisted of eight questions rated using five-level Likert-type scale with the following format: 1 – strongly disagree, 2 – disagree, 3 – neutral, 4 – agree, 5 – strongly agree. The results of the survey are presented in Table 1. The survey also included two questions about what student liked about the lab and what they wanted to be improved. The compilation of the most common answers is presented in Table. 2.

Table 1. Results of MECH 304 Lab 1 Student Experience Survey

Question	Day Students (Average)	Night Students (Average)
I would take another course with hands-on labs.	4.7	4.6
The lab was a good addition to the course.	4.2	4.1
I liked doing the lab without understanding the outcome.	3.8	3.9
I liked the learning group dynamics in team environment.	3.7	4.1
Some things in the lab were not explained well.	3.1	3.9
I would have preferred another method of teaching.	2.3	2.6
The lab material was too difficult to understand.	2.3	2.3
I did not learn much in the lab.	2.1	2.6

As it can be seen from the survey results, students do enjoy courses with labs and hands-on experience. They did not mind participating in this laboratory without having a thorough understanding of everything they did. It was mentioned to the students before the Lab 1 started that they were only asked to present test results and did not need to analyze or discuss the results. It was explained that at the conclusion of Lab 1 the students would have the necessary knowledge needed to compare and understand the relationships between different heat treatment parameters and obtained microstructures and subsequent mechanical properties. Students agreed that the lab was not difficult and that they learned. The only difference in results between day and night students was for a question about how the laboratory was explained. The evening sections rated that explanation as unsatisfactory however this group of students was faced with change of instructors due to health issues of an adjunct professor teaching them during the first few weeks of the semester. The adjunct has been replaced by the instructor of day student sections.

Table 2. The most common answers to MECH 304 Lab 1 Survey questions

What did you like about this lab?
"It was hands on and we got to see what grain structures looked like".
"It was an interesting lab that kept me engaged. The lab was a lot better than most of the labs I have taken so far".
"We were allowed to work at our own pace".
"Learning about how materials are tested for ductility and seeing the microstructure was helpful".
"We actually got to do everything ourselves".
What do you think could be improved?
"Written instruction and steps".
"There was trouble trying to find time where our schedules worked so we could be supervised".
"Better explanation of the procedure and operation of the equipment".
"An overview and quick lesson about the microstructures would have made it easier to write a good report".
"I think a sheet explaining in detail how to use each equipment would help".

The answers to the supplementary questions show that students enjoyed the lab. They felt engaged and liked to feel independent and competent. They requested better instructions and written operating procedures.

The course MECH 304 was also evaluated by students at the end of the semester. Comments regarding the laboratory part of the course included:

"I enjoyed learning more about materials and working on material projects in the lab".

"Good hands on experience with the labs. I learned a lot from the last tempering lab".

"The first lab should have been done after we had learned the material, not before when we had no context of what we were doing".

"The concept of the lab and it being supper hands on was great but it's not without its faults…"

The end-of-semester course evaluation confirmed that students enjoyed the hands-on experience but more order and instruction is required in future offerings.

Conclusions

The Engineering Materials with Lab course taught at The Citadel provides hands-on experience that has been implemented in order to facilitate the theory taught in the classroom. Due to time constraints Lab 1 was completed by some groups before the theory was introduced but the compilation of the results was presented immediately after all related topics were covered. The

results from reviewing the first offering of the course with the new laboratory schedule have been presented and do suggest that the approach is effective at engaging students in the experimentation and in connecting academic concepts between usually challenging topics. Ongoing efforts to improve student learning and modify the lab experience was based on a blind student survey, oral discussions as the lab is being conducted, grading of lab reports and direct opinion from students commenting on how they understand and learn through practical experiences. Both students and their instructor agreed that the laboratory required better written instructions and operating procedures. Finally, in the classroom there have been an increased enthusiasm while discussing materials and their properties.

References

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Monika Bubacz

Dr. Monika Bubacz is an Associate Professor in the Department of Mechanical Engineering at The Citadel. She received both her B.S. and M.S. in Mechanical Engineering from Poznan University of Technology in Poland, and the Ph.D. in Engineering and Applied Science from the University of New Orleans. Before her current appointment she has worked for Mercer University, Center for NanoComposites and Multifunctional Materials in Pittsburg, Kansas and Metal Forming Institute in Poznan, Poland. Her teaching and research interest areas include materials science, polymers and composites for aerospace applications, nanotechnology, and environmental sustainability.

Luiz Dos Reis

Luiz Dos Reis is a mechanical engineer student at The Citadel: Military College of South Carolina. He moved from Brazil to the United States at age eighteen and before long completed a six year contract in the United States Air Force with a career in maintenance production management in the civil engineer squadron. He has tutored mathematics, from college algebra to calculus, for The Citadel and Trident Technical College for a total of 378 hours and certainly enjoys teaching. His interest is in renewable energy and instructional media production for education.