2006-2503: A COLLEGE-WIDE MATERIALS TESTING LAB: A UNIQUE APPROACH FOR HANDS-ON EXPERIENCE

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Introduction

Engineering education requires the assimilation of knowledge of physical phenomena. To understand mechanical behavior and subsequent design parameters, it is essential to directly observe the deformation of materials. However, the physical and financial resources required are extensive.

At the University of Illinois at Urbana-Champaign the approach is to establish college-wide laboratories to serve all students in all departments. The Mechanical Testing Instructional Lab is a college-wide lab dedicated to mechanical property experimentation. In this paper, there is a description of the equipment, relationship to courses, typical procedures and general administration.

History[1]

In the early 1970's, state budget cuts forced the elimination of funding for instructional equipment and laboratories. Rapid changes in technology, particularly the growing application of computing, presented challenges to maintain quality in the instructional laboratories in the College of Engineering.

A funding program in the 1980's helped to revitalize some of the engineering lab facilities; however, many objectives were unfulfilled. The realization of the importance of computer technologies by industry prompted significant contributions by technology companies. The Illinois Society of Professional Engineers promoted the establishment of the Illinois Engineering Equipment Grant Program for the purchase of lab equipment and other resources.

The need to use College of Engineering resources more effectively was recognized. Advances in computer systems and applications made the integration of computer facilities an obvious area for consolidation. Before 1990, there was duplication of computing workstation hardware and software by individual departments. Typically, software had to be accessed within the physical boundaries of a particular department. In 1991, the first Engineering Workstation Laboratory was established. The expansion of these centers opened access to computing services from many locations across the campus. Two other college-wide facilities were created in the early 1990's, the Computer-Integrated Manufacturing Laboratory and the Control Systems Laboratory.

A faculty group began consideration of a mechanical properties laboratory in 1992. The study of the mechanical behavior of materials was an important part of many departmental curricula; however, departments did not have the resources to finance instructional facilities with first-class equipment. Typically, experiments were conducted in facilities that were heavily used, did not allow hands-on experience, and incorporated equipment that was old or borrowed from research programs. The usual format was a teaching assistant conducting the experiment while a group of students watched. Equipment was often located in a research setting and the tests were difficult to observe. The primary need was an introductory laboratory that would allow students access to quality equipment, provide maintenance of equipment and updated software, and train teaching assistants.

Space was acquired and equipment acquisition began in 1994. Departments transferred some equipment and purchase orders were issued for universal test machines and hardness testers. The lab was initially directed as an independent entity by the College of Engineering mechanical testing research laboratory. Research personnel provided a firm base for management independence, fundamental materials knowledge and expertise in test procedures, hardware and software.

In the fall semester of 1994, a full-time manager was hired and the first classes used the facility. By the next fall, all labs for the basic materials behavior courses in General Engineering, Mechanical Engineering and Theoretical and Applied Mechanics/Civil and Environmental Engineering labs were held in the lab.

Primary Objectives

Course instructors and teaching assistants change. A permanent lab staff dedicated to instructional tasks provides a consistent environment and expertise for the equipment, the experiments, and the instructional procedures. The overall purpose of the facility is to provide equipment, materials and supervision that cannot be cost justified by individual departments. A primary emphasis is giving the individual student hands-on experience. It is important that each student gets as much time as possible working with the equipment and observing actual results. The highest priority for the use of the lab is always for scheduled undergraduate laboratory instructional courses.

Lab Space

The majority of the lab is located in one large 1780 square foot space divided into four primary testing areas. Equipment is selected so that even inexperienced students can safely operate it and is arranged for student access and ease of supervision by lab instructors. Lab enrollment is strictly limited to sixteen students to insure an environment for the hands-on experience and safety. TAs are assigned by the individual departments and supervise the students. In general, two TAs are in charge with each one responsible for one-half of the class (six to eight students).

Basic Testing

There are four stations for the testing of strength properties. Each station has a testing machine, calipers, a desktop computer, a Rockwell hardness tester, and a stereomicroscope.

The Instron 4483 universal testing machine has a load cell capacity of 100kN and a mechanically driven crosshead with rates up to 508 mm/min. This limited speed eliminates the possibility of sudden displacements that might be hazardous to students. Tensile, compressive and bending tests are conducted. The fixtures are secured with clevis pins to facilitate quick changes of test configurations. Wedge-action tensile grips allow easy change of grip inserts for round and flat specimens. Extensometers measure strain directly. Each test machine has the GPIB (IEEE-488) option installed to enable test control and data acquisition by a desktop computer.

Hardness data are assessed on Wilson Rockwell testers that have fixtures for plates, round stock and Jominy bars. Each station has digital calipers and stereo microscopes to examine surface features, particularly fracture morphologies. Two other hardness machines are located in the area. A Brinell tester is used in hardness labs and a Vickers micro-hardness tester is employed to measure hardness profiles in weld zones.

Vulcan bench top furnaces with temperature ranges to 1200˚C are employed for specimen preparation including the heating of steels for heat treatment labs and the melting of mixtures for phase diagram studies. A 200g capacity scale with a 0.01g resolution is used to weigh phase diagram materials. The furnaces are programmable to set heating cycles and delayed starts. Steel tensile specimens are quenched in oil and water and there are two tanks for Jominy bar quenching for hardenability experiments. Grinding stations and belt sanders with vacuum bases are set up to clean specimens. Students use these machines to remove scale from heat-treated specimens.

Impact Area

The impact section is arranged to accommodate up to ten students. Testing is conducted on Dynatup® testers that are equipped with force transducers to allow the collection of force vs. time data. These data are integrated to obtain energy absorption data. Two testers are configured for Charpy tests and two others are set up for clamped plate impact experiments.

Charpy v-notch tests are conducted on 1045 normalized steel and aluminum alloy specimens. Specimens are tested at room temperature and after soaking in ice water and boiling water. Data for the 1045 steel specimens show a definitive fracture transition in this range of temperatures. Sheet specimens of HDPE, polypropylene, and PMMA are cut into small plates and clamped for impact tests. The test temperatures are the same as those used with Charpy tests. PMMA specimens exhibit a definitive transition.

The use of materials that show a transition at relatively ordinary temperatures eliminates the need for very low or very high temperatures that might present safety hazards. Also, the students can realize that this phenomenon may occur in common operating environments.

Bench Area

The bench area is used for creep testing, corrosion testing, and other bench-top experiments. Sixteen students can be accommodated. The portable apparatuses for rolling and torsion experiments are set up in this area. For these tests, the limit is eight students. The rolling mill is used to roll brass strips to study work hardening. Torsion experiments are conducted on steel, aluminum and plastic specimens.

Metallograph and Fracture Mechanics

A Nikon metallurgical microscope with objectives from 5X to 100X is utilized for examination of microstructures. The images are projected on a TV monitor for instructional purposes and cursors generated by a Boeckeler measurement system may be superposed on the display to measure the sizes of microscopic features. Microphotographs and other visual aides are posted to assist instruction.

A servo-hydraulic tester is used for demonstrations of fracture toughness, K_{IC}, testing. This machine is used to propagate the fatigue crack and to perform the test. A video image from a microscope is displayed to observe the growth of the crack during testing.

Photoelasticity Area

A polariscope is set up in a separate room for photoelastic demonstrations and studies. Images are displayed on a TV monitor and a Boeckeler measurement system is used for direct measurement of fringe patterns that may be printed on a photographic printer. A routing table, drill press and band saw are set up for specimen preparation.

Data Recording

Data recording and data display as well as Instron machine control are performed on computers running LabVIEW® software from National Instruments. This software permits the customizing of data handling and machine control on look-a-like panels for all test applications. All data files have a common ASCII tab-delimited format and are transferred to a server for student access.

The typical program structure starts with screens for calibration and test machine parameters. Students enter specimen data on a header panel. Data recording is started and halted on the run panel. Experimental data are plotted on the screen as a chart or graph during the test to give immediate feedback. A final plot of the data provides an overall view of the test data and windows for the entry of measurements at the end of the test.

Computers for Instron control have GPIB PCI cards installed. All other computers have A/D boards installed. Modules with BNC inputs are plugged into the A/D boards. SCXI analog modules are plugged into these boards for thermocouple data collection and LVDT measurements.

Lab Session Format

The tensile test lab is usually the first lab of the semester for all courses and is used here as an example. The two-hour period usually begins in the lab classroom with a *brief* presentation by the lab instructor. Course instructors provide PowerPoint slides to correlate the lab experiments and lecture material. It is emphasized to the TAs that student time in the lab should be maximized.

When the students enter the lab, each TA takes one-half of the students and demonstrates the procedure for the tension test on a cast iron specimen. Correct procedures for hardness measurements, measurement of dimensions and machine set-up are emphasized. Since cast iron is brittle, the test is relatively short and the TA needs little filler material. At the completion of the test, students are divided in to groups of three or four. Typically, tests are conducted on a plain carbon steel, an aluminum alloy, 304 stainless steel, and PMMA. Since there are four specimens, each student can adopt a specimen and perform the entire sequence: conducting hardness tests, measuring the dimensions, installing the specimen and setting up the extensometer. In the LabVIEW program, test parameters are set and specimen data are entered. After running the test, the student removes the specimen, takes final dimensions and enters the data on the computer. The group members are encouraged to coach each other to develop a team relationship.

Less complex tests require less demonstration. For example, the students watch a short movie showing the procedures for the bending test. They are already familiar with the Instron machine and the software, so the TAs can concentrate less on procedure and more on material behavior.

The small groups promote teamwork and camaraderie. For the impact tests, there are usually only two students at any of the four impact stations. The students measure dimensions and enter data for each specimen at their station. There are four tasks to run a test: instrumentation is enabled, the specimen is set into the fixture, the enclosure door is secured and the impact carriage is dropped. Two more students must be recruited from other groups. When all four stations have completed the set up procedure, the tests are run in sequence: the two Charpy tests, then the two polymer plate tests. For the hot and cold specimens the time from removal out of the temperature bath to impact becomes critical, therefore the team must coordinate their tasks for a successful test.

Four person teams are also required for the Jominy end quench tests and the cooling curve tests in phase diagram labs.

The only tests conducted in the lab that are not student operated are the rolling of brass wedges for the cold work lab and the K_{IC} test. Because of safety issues, a TA operates the rolling machine. Students perform all measurements of dimensions and hardness. The lab manager conducts the K_{IC} test since the servo-hydraulic apparatus is complex and time is limited.

Management and Administration

A full-time lab manager directs the lab. The manager is directly responsible to the Associate Dean for Academic Affairs for the College of Engineering. An advisory committee reviews lab operations and makes suggestions for equipment acquisition and lab procedures. Every department that has labs in the facility has a member on the committee.

Operational funding is provided through tuition surcharges levied on all engineering students. These funds are designated for computer accessibility and laboratories and can only be used for instructional purposes.

Two-hour slots are permanently allocated to individual departments on a semester basis and are periodically reviewed for redistribution. Fridays are kept open for TA training sessions. Departments write their own lab manuals and assign their own instructors to conduct the lab sessions and to grade reports. The lab provides test specimens, maintains equipment, and trains the teaching assistants.

A full-time staff ensures that a high level of expertise is maintained and there is continuity from semester to semester. Experience over time leads to more relevant instructional emphasis and more efficient procedures. In particular, maintaining the schedule of tests within a lab session is often critical for the timely completion of all tests.

TAs attend two-hour training sessions for each lab. Basic theory, test procedures and the relevance to the course material are discussed. In the lab, all tests that the students will conduct are run and the results are discussed. If a demonstration is a part of the lab, each TA practices the presentation.

New TAs tend to help the students too much. They are instructed to be hands-off and to allow the students to perform all steps of the tests. They are admonished to avoid touching the machinery, but rather to coach and talk the student through any problems.

The teaching faculty is relieved of concerns with laboratory procedures and can concentrate on the integration of the lab experience with course subject matter. There is practically a guarantee that the tests will work as envisioned, that specimens will be supplied and that the students will be in a safe environment. The manager works closely with the course instructors to coordinate a schedule for the semester and to ensure that the tests and materials are appropriate to the course.

Advantages Realized

The primary goals of the 1992 organizational committee have been achieved. Students get hands-on experience operating first-class testing equipment. Duplication of equipment is avoided to more effectively distribute capital resources and to utilize space more efficiently. Teaching faculty are ensured that testing is performed safely and that there is relevance to their course material. Larger departments do not have to maintain an instructional facility. Smaller departments have access to equipment and resources that they cannot cost justify.

Annually the lab serves about 550 individual students in labs for materials courses. Counting each time a student attends a lab as a "visit", there are nearly 4000 visits during an academic year.

There are economies of scale. Since there are several identical machines, it is economical to maintain a full complement of spare parts and annual maintenance visits by factory-trained personnel are justified. Some specimens are machined in large production runs to reduce item expenditures.

Different departments conduct different tests and some equipment is unique for those tests. Faculty becomes aware of additional tests that might be germane to their course. For example, only one course runs a complete creep lab. However, since the apparatus is available, other departments have had the test set up as a demonstration during another lab.

The lab is a resource for other student courses, particularly senior capstone projects. The most commonly used apparatus is the hardness tester.

This efficiency has its costs. Effective utilization of time means that more tests can be conducted in a lab session. For example, there is an annual consumption of 850 metal tensile specimens. Individual departments surrender control of equipment and facilities.

Evaluation

The basis for student assessment of this instructional facility is challenging. It is difficult to isolate the lab facility itself from the course and the effectiveness of TAs. The best method has been to set up focus group meetings at the end of the semester. The feedback has been positive with particular emphasis on gaining hands-on experience.

For written evaluation, the fundamental question is, "What did you learn?" Students are asked to self-evaluate their own progress by rating their confidence to perform testing tasks before the course and after the course has been completed. For example, is there self-confidence that the student can take a tensile specimen, make all measurements, then set up and run the test and evaluate the data? They rate their own ability to conduct the various types of tests on a scale of 1 to 5. The use of digital calipers is used as a "control". The pre-course responses are usually zero, not familiar with the test. Most post-course responses are 4 or 5.

Conclusion

The Mechanical Testing Instructional Lab successfully provides a hand-on environment for undergraduate instruction. The lab represents an efficient use of resources, relieving individual departments from maintaining duplicated equipment. A full-time manager administrates the facility as an independent entity in the College of Engineering. Equipment is selected and arranged for student use. TAs are trained to instruct the students in proper testing procedures. Student response is positive.

Bibliography

1. Maureen L Tan, College-wide Instructional Laboratories, *Engineering Outlook*, **36**, 1, Winter 1994-95.