Virtual Steel Lab

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ABSTRACT

A completely online (virtual) laboratory experience has been implemented in a junior/senior level materials science/selection course at the University of North Dakota. The complete laboratory experience comprises a set of five week-long activities based around various properties of steel alloys. Data is accessed from a central webpage through a series of hyperlinks and nested JavaScript lookup tables. Each activity is based on a short (two- to four-page) set of instructions and supported by background information including case studies and testing standards. Students are instructed to complete a lab report per the instruction sheet which is submitted in hardcopy to the instructor. The results of student assessment of the virtual laboratory experience are presented. They show an overall favorable response from students to using the virtual format.

INTRODUCTION

In 1989, the University of North Dakota School of Engineering and Mines established a Distance Engineering Degree Program (DEDP) to deliver Bachelor of Science engineering degrees to distance learners. UND currently offers the only ABET-accredited undergraduate engineering programs at a distance. One requirement of the DEDP program is that students spend up to three weeks each summer on campus completing laboratory assignments for courses taken during the academic year. The summer on-campus commitment for completion of the laboratory component of the program is a major hurdle for DEDP students. In the past, even though many of the companies supported their students through tuition assistance or tuition reimbursement programs, the travel costs incurred by the students, the loss of holidays and time away from work and home for completion of the laboratory assignments have limited participation.

Using traditional ‘hands-on’ assignments, the current summer laboratory requirements for DEDP students are 3-5 days on campus for a one-credit course, 7-9 days on campus for a two-credit course, and up to 14 days on campus for a three-credit course. Summer lab sessions typically also involve extensive weekend work. UND recently initiated a project with the stated goals of reducing DEDP student campus time for laboratories by 50% while maintaining parity between the laboratory experiences of the on- and off-campus students. This was to be accomplished by replacing 25% of the traditional assignments with online labs, in which hardware exists at the University and is operated over the internet, and 25% with virtual or simulated labs in which the raw data for the assignment has been compiled for the students in a central webpage or file. This paper describes the structure, content and evaluation of a virtual lab used in a junior level materials science/selection course, ME 313.

TRADITIONAL LABORATORY STRUCTURE

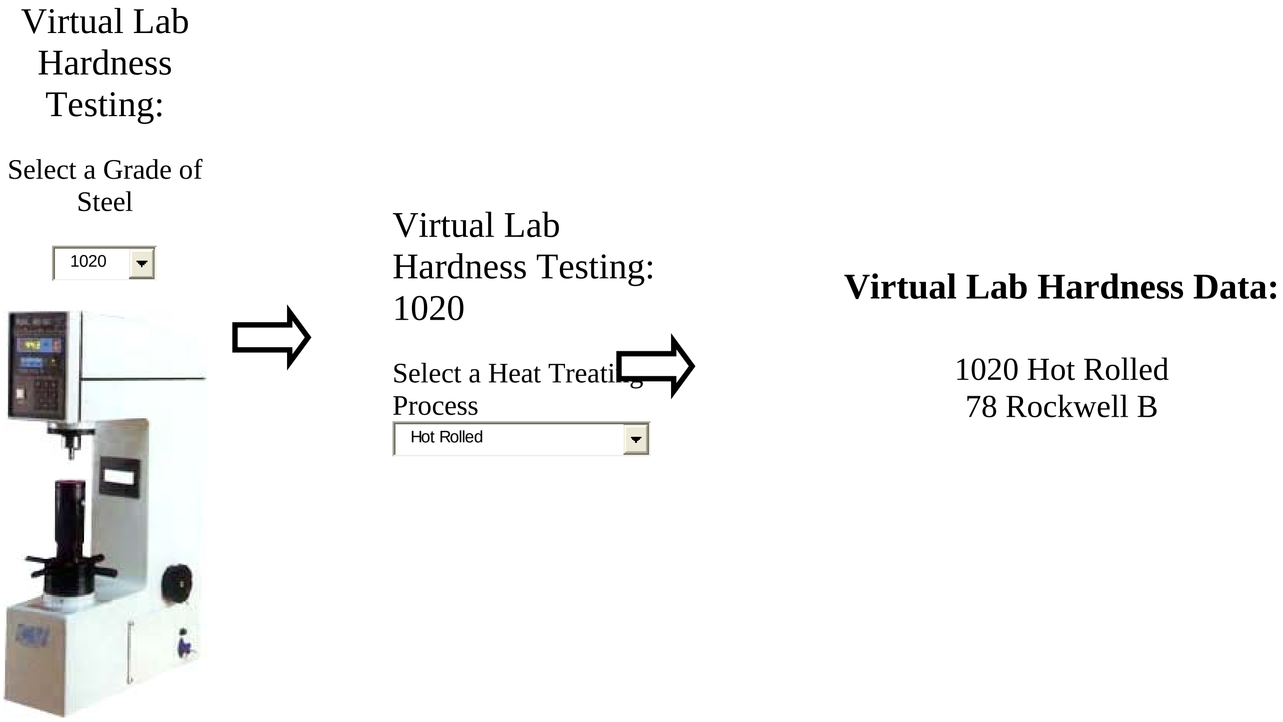
The goal of the half-semester lab experience in ME 313 is to give the students an understanding of the mechanical testing and microstructural examination of materials. Students have traditionally conducted a series of hands-on activities using a variety of steel alloys. The specific activities chosen were representative of existing lab equipment available at UND. Five laboratory experiences from the following broad subjects were assigned:

1. **Microstructural examination**: 1020, 1095 spheroidized, 1095 furnace cooled and 1095 quenched samples were polished and examined. The ASTM grain size of the 1020 samples was measured by the students.
2. **Heat treating/Hardness:** 1020, 1095, 4340 and 4140 samples were austenitized and quenched. Hardness was measured along the length of the specimen.
3. **Mechanical testing**: Charpy impact and tensile testing were performed under a variety of conditions. Impact data were taken at the temperature of liquid nitrogen, ambient and after heating for 20 seconds with a torch. Tensile testing involved testing samples of both ductile and brittle steels.

Each lab session lasted from 2 to 3 hours and students were given a week to complete the final report.

VIRTUAL LAB STRUCTURE

The virtual lab is designed to retain the general topical areas of the traditional lab assignments. The content areas are divided into five week-long lab assignments. Individual lab assignments, data, micrographs and background information are accessed through a password-restricted central webpage via hyperlinks. Temporary access to the webpage can be given on request. An assignment typically consists of a two- to four-page document containing a brief description of each activity, hyperlinks to specific procedures and a series of short activities in which the students are required to access and analyze a variety of information. The data (numerical and pictorial) is typically nested within JavaScript lookup tables. A sample lookup table truncated to only two selections is shown below within the required html scripting. Figure 1 illustrates an example



Virtual Lab Hardness Testing:

Select a Grade of Steel

1020

Virtual Lab Hardness Testing: 1020

Select a Heat Treating Process

Hot Rolled

Virtual Lab Hardness Data:

1020 Hot Rolled
78 Rockwell B

Figure 1: This is an example of the on-screen result of the nested JavaScript lookup tables described above. In this case the data is for Rockwell hardness values.

of what the students might see as they navigate the lookup tables. The JavaScript coding for a lookup table was found on the internet.

```
<html>
<head><title>Fracture Images</title></head>
<body>
<p><bold><font size=+3>Microstructural
Images:</font> </bold></p>
<bold><font size=+2>Select a Grade of Steel
and Thermal Processing</font> </bold>

<form name="a814">
<p><select name="a823" size="1">
<option selected value="1020F.htm">1018
Furnace Cooled</option>
<option value="1020a.htm">1018 Air
Cooled</option>
<option value="1045Furnace.htm">1045
Furnace Cooled</option>
</select>
 <input type="button" value="Go"
onClick="location=
document.a814.a823.options[document.a814.a8
23.selectedIndex].value"></p>
</form>
<img src ="1018Grain.jpg" WIDTH =400
HEIGHT = 300 >
</body>
</html>
```

For some assignments, video clips of actual experiments being performed are also included. Though not directly required for completion of most lab activities, each background section typically contains references to case studies, descriptions of testing standards and additional information that can be used at the discretion of the instructor to supplement the main laboratory experience. The final lab reports are submitted in hardcopy by the students to the instructor. Several of the individual lab sections are described below.

MICROSTRUCTURAL EXAMINATION

Micrographs of several steel alloys, including 1018, 1045 and 1095 were collected in the following conditions:

Furnace cooled
Air cooled
As quenched
Quenched & tempered at 400ºF
Quenched & tempered at 1000ºF

Spheroidized microstructures of the 1045 and 1095 alloys were also included. Each figure caption included hardness values (edge and center) and a brief description of the microstructure/phases present. The images can be accessed using nested lookup tables written in JavaScript, as described above.

For this lab it was very nice to have an entire set of coordinated microstructures and hardnesses available for a variety of heat treatments. The experience of grinding and polishing (by hand at our university) was lost, but hopefully the lab is enhanced by processing more images. Also, historically the student images produced by manual grinding, polishing and etching have been “high quality” less than 50% of the time. With the virtual lab, each student has access to good microstructure data for each sample and can concentrate on analyzing the structure of the material. The grain structure measurement portion of the virtual lab was considered to be equivalent to the historical experience.

HEAT TREATING/HARDNESS

There is a certain “gee whiz” quality of seeing a glowing red steel specimen coming out of the furnace and getting quenched. It was attempted to capture this by including a movie of the Jominy quenching process in the virtual lab. There were some problems with optimizing presentation of the video over the internet. AVI video images took too long to download and were finally converted into flash files with Macromedia. For the files to play, the PC must have the free flash player installed. If the PC does not have the player, the user is prompted to download it.

A Jominy curve is a plot of hardness versus distance from the quenched end. While the students are not required to perform Rockwell hardness tests as part of the virtual lab, a simple do-at-home heat treat experiment was added to compensate. An ordinary black binder clip (Figure 2) can be used to demonstrate heat treating and the martensitic transformation. It also illustrates the differences between high-carbon steel and low-carbon steel with respect to brittleness, ductility, formability, strength and springback.

Figure 2: The black portion of the binder clip is tempered spring steel that has been electroplated with a black oxide coating [1]. This material is hypothesized to be 1074 carbon steel [2].

When the material is heated and quenched, the material is as crunchy as burnt toast. Upon tempering (heating and cooling slowly), ductility is restored. The students are asked to compare this behavior to that of a typical paperclip which is made from a low-carbon steel. Quenching has little to no effect on the properties of the paperclip.

Within the lab assignment, JavaScript lookup tables for time-temperature-transformation (TTT) and Jominy plots were added. Color images of tempering colors and furnace colors were also included. These helped to give students an appreciation for the fact that heat treating, before it became scientific with modern instrumentation, was more of an art form practiced by those with an experienced eye for the various colors. They also allowed students to look at data from a large number of samples and consider properties such as hardenability, carbon content, *etc*.

TENSILE TESTING

A series of nested lookup tables for materials (*i.e.* 1020, 1040, 1060, 1080, 1095, 4140 and 4340) and heat treats (*i.e.* annealed, spheroidized, normalized, quenched and tempered to various tempers, *etc*.) were set up with JavaScript for mechanical properties. Look up tables were also used for stress strain curves and fracture images (macro and micro). Students were asked to compare these results with changes in microstructure due to carbon/alloy content and heat treatment. They were also asked to design an experiment for measuring the modulus of elasticity of nylon fishing line. As part of the assignment, the students were asked to investigate the fishing line available in local stores and provide information such as manufacturer, dimensions and pricing.

Admittedly, it is important to see a ductile tensile specimen necking down and “feel” the impact of fracture. Hopefully, this experience was somewhat captured with a video image. Even the impact of fracture was somewhat shown by the image jiggle during fracture. Some students did comment they would have preferred to have controlled the tensile test machine. It should be noted, however, that because of the complexity of the tensile test machine, tensile tests were historically done as a group lab with the instructor controlling the test machine.

ASSESSMENT

After completing the five virtual lab assignments, the students were asked to assess the virtual lab by filling out a questionnaire. The questionnaire contained a section where students were asked to rank various aspects of the virtual lab on a scale of ‘1’ to ‘10’ with ‘10’ being the highest and a second section for short answer responses to gain insight from the students about overall impressions and areas for improvement. Results from several of the numerical ratings are listed in Table 1.

Assessment Area	Mean Ranking	STD
Range of topics covered in the virtual lab assignments	7.7	1.8
Range of data available from the virtual lab	7.4	1.4
Value of movies accompanying virtual lab assignments	7.2	2.7
Ease of use of the virtual lab website	8.4	1.5
Overall value of virtual lab assignments to ME 313	7.0	2.1

Table 1: Results from the student assessment of the virtual lab

The assessment results show that the students were satisfied with not only the structure and content of the virtual lab itself but also the value it added to their classroom experience.

In the short answer portion of the questionnaire, several students specifically identified the trade-off between the additional information that can be packaged in the virtual lab and the loss of the hands-on experience of performing the lab. Interestingly, among the students who specifically identified this compromise, there was no clear consensus about which was more important. Some students mentioned the advantage of processing "clean" data and seeing a wider variety of information and other students regretted not performing the experiments themselves. (Having discussed internet labs for years, this author concludes either you are receptive to the idea or not.)

OVERALL IMPRESSIONS

Perhaps the debate about virtual labs vs. hands-on labs will never be resolved. Personal inclination towards experimentation can color the views of both students and professors. Regardless of these preferences, however, the virtual lab can be viewed on many levels, including an improved method of presenting an assortment of information. With the hundreds of mechanical properties and over 80 images and figures, the hyper linking and lookup tables proved to be a very good way to organize a large amount of data for easy access.

FUTURE PLANS

It is hoped to make the virtual lab more "hands-on" in the future by making more interactive experiments. Currently, the lab consists primarily of static lookup tables which are accessed by the students based on inputs for alloy type, processing, *etc*. Ideally, we would like to display experimental data dynamically, *i.e.* as if the students were gathering it themselves in the lab. For example, strain rate greatly affects tensile properties. One possibility is an interactive graphic where the students input material type and strain rate and the computer draws the stress strain curve at the appropriate speed. Similar activities can be envisioned for the other topic areas.

REFERENCES

1. http://www.officemax.com, accessed 4/22/04

2. Cubberly, W.H., *Metals Handbook, 9th ed.—Properties and Selection: Irons and Steels*, American Society for Metals, Metals Park, OH, 1978.

BIOGRAPHICAL INFORMATION

Matt Cavalli is an Assistant Professor at the University of North Dakota. His primary teaching areas are engineering mechanics and materials behavior.

George Bibel is a Professor at the University of North Dakota. He has done research for NASA and the Pressure Vessel Research Council and has been involved with internet education for many years