Session 2164

An Innovative Materials Laboratory Collaboration

James P. Bandstra, University of Pittsburgh at Johnstown
Richard J. Henry, Concurrent Technologies Corporation

Abstract

The University of Pittsburgh at Johnstown offers a Materials and Manufacturing Laboratory course in collaboration with Concurrent Technologies Corporation. This paper describes the collaboration, the benefits of the collaboration, and the materials laboratory experiences that the collaboration provides for the Mechanical Engineering Technology students.

Objective

The objective of this paper is to provide a description of how the University of Pittsburgh at Johnstown (UPJ) and Concurrent Technologies Corporation (CTC) collaborate to provide a valuable educational experience for engineering technology students. A description of the motivation for pursuing this collaboration and each organization's respective role in fulfilling the collaboration is presented. In addition, examples of typical laboratory experiments are presented in the context of those motivations and roles. The authors hope that the collaboration described may provide guidance for the ASEE community to leverage this approach with their respective local resources.

Goals of the Collaboration

A basic tenet of the educational philosophy of the Mechanical Engineering Technology department at UPJ is to teach the fundamentals of engineering in a 'practitioner' context. To do this, UPJ seeks experienced engineers to serve as faculty members. While insightful teachers can often use their practical experience to enlighten and place the academic content into an industrial context, the student still can benefit from first-hand experience in that industrial setting. In selected situations, students are able to secure internships with local engineering and manufacturing firms which provides them with first-hand experience in the work place. But in the still economically depressed Johnstown area, there are not enough internships available to serve all students. By teaming with CTC to provide laboratory experience in the work place, UPJ is able to give all students completing the Mechanical Engineering Technology program the first-hand experience of working with practicing engineers and technicians in their work place.

CTC is organized as a non-profit educational corporation whose primary business activity is to perform engineering services work for the U. S. government. These services include information technology and environmental services as well as problem solving in materials and manufacturing. As part of its mission, CTC is active in transferring information to the technical base through publications and is charged with transferring the outcome of problems solved to the domestic industrial base. Providing engineering students with laboratory experiences as well as internships is one cost-effective and efficient way to transfer that knowledge. Upon graduation those students carry that knowledge with them to the industrial base.

Thus, UPJ and CTC have mutually compatible goals and a vested interest in the education of the next generation of engineering students. These goals can be summarized as:

- Students will learn in a 'working' environment as well as an academic environment - ideally providing a basis for lifelong learning habits
- Students will learn from active practitioners - placing factual information into a 'utile' context
- The educational experience for the student will be broadened and deepened by working with practitioners
- Local industry and engineering companies will strengthen the educational experiences of engineering students, thus better preparing them for rapidly becoming productive in the work place upon graduation.

Of utmost importance to the engineering education community, collaborations similar to that described in this paper allow the university to leverage existing local resources, thus avoiding using scarce university resources in duplicating capabilities.

Background

The University of Pittsburgh at Johnstown (UPJ) offers baccalaureate degrees in Mechanical Engineering Technology (MET) in its Engineering Technology Division. While focused on mechanical design as a prime educational outcome, the mechanical engineering faculty recognize that a fundamental understanding of engineering materials and related manufacturing processes is critical for the engineering technology graduate to be able to effectively function in today's concurrent engineering paradigm. Most curricula in mechanical engineering and engineering technology offer courses in materials and manufacturing and many include lab experiences along with these courses. Adequate facilities must be provided for these laboratories as required by ABET criteria:

> EAC criteria: "Classrooms, laboratories, and associated equipment must be adequate to accomplish the program objectives and provide an atmosphere conducive to learning. Appropriate facilities must be available to foster faculty-student interaction and to create a climate that encourages professional development and professional activities."[1]
>
> TAC criteria: "Adequate facilities and financial support must be provided for each program in the form of:

a. suitable classrooms, laboratories, and associated equipment necessary to accomplish the program objectives in an atmosphere conducive to learning
b. laboratory equipment characteristic of that encountered in the industry and practice served by the program"[2]

Significant planning and funding are required for the implementation of well-designed materials laboratory courses[3]. Different schools have developed various integrated courses and laboratories to meet this need for the materials lab[4,5].

To provide a fundamental grounding in materials and manufacturing, the MET curriculum originally included a single junior level course in Materials and Manufacturing. However, this course consisted primarily of coursework taught from a text, enriched by selected demonstrations conducted in the division machine shop. Recognizing the need to broaden this aspect of the students educational experience, in the late 1980's the faculty modified the MET curriculum to include separate courses in Materials and in Manufacturing and began to develop a one semester laboratory course which would provide experiments in both the principles of engineering materials and in their related manufacturing processes.

Fortuitously at that time, the National Center for Excellence in Metalworking Technology was established in Johnstown, only two miles from campus. Operated by CTC and funded by the U.S. Navy, the metalworking center had as its mission the solving of metalworking problems associated with the manufacture and sustainment of Navy weapons systems and the transfer of those solutions to the domestic industrial base. UPJ faculty, some of whom were working part time at the metalworking center, recognized that, if UPJ students were able to access the test and engineering facilities at CTC, the students' educational experiences could be enriched. Furthermore, by leveraging the CTC facilities, the University could offer a greater variety of materials and manufacturing educational experiences than would be available if limited by university resources. CTC's engineering management recognized that, by allowing the students to conduct experiments using CTC facilities, CTC would both fulfill, in part, its mission as a non-profit educational corporation and help prepare engineering graduates for careers at CTC as well as other industry and engineering organizations. Thus was born this unique opportunity for UPJ to leverage local resources to develop the planned materials and manufacturing laboratory course.

Organizational Roles and Experience

UPJ faculty determined the types of laboratory experiments that were germane to the materials and manufacturing laboratory course. For each of these experiments, the educational objectives were defined paying particular attention to the aspect of materials technology that would be useful to the engineering graduate. For example, a basic tenet of the materials course it to teach the student that the engineering properties of a given material are dependent on the internal structure of that material - and furthermore, that structure is determined primarily by the manufacturing process by which the material is made. Thus, if one is going to have the students complete an experiment showing the effect of rolling on the mechanical properties of aluminum, it is insightful to provide the student with an opportunity to observe and evaluate the differences in internal structure that are evident through examination using an optical microscope.

UPJ faculty and CTC engineers then discussed the various experiments and their objectives. The CTC engineers were able to provide insights that helped to properly focus the educational objectives. In some cases, the CTC engineers noted that a particular educational objective was impractical either because of limitations in the availability or capability of the equipment available or because of time constraints.

To execute the laboratory course, a UPJ faculty member and a CTC engineer or technician coordinate each laboratory experiment. The students, divided into groups of three or four, complete four to six experiments during the semester course. The number of experiments may vary from term to term depending on the availability of equipment and the interests of the faculty member and students. Whenever possible, as permitted by safety and work rules, the students are required to complete the experimental work themselves. In those situations where the students are not permitted to do so, experienced CTC engineers and technicians conduct the experiments with 'assistance' as appropriate by the students. In general, the CTC engineers and technicians are active participants in the educational process, asking and answering questions and encouraging discussion. Formal laboratory reports conforming to an industrially inspired format are required from each group of students for each experiment. The UPJ faculty member does all grading.

Experience

The materials and manufacturing laboratory course experiments performed at CTC have varied over the ten years that the laboratory has been conducted. This is partly due to the interests of the faculty involved as well as an attempt to update and vary the content of the course based on prior years experience. Laboratory experiments have included recovery, recrystallization and grain growth using aluminum that was cold rolled as part of the experiment; the effect of heat treating on the properties of steel; the applicability and limitations of various hardness tests; the development of forming limit diagrams for upset forming; the effects of cold working on mechanical properties and an experiment in sheet metal forming. In addition, experiments using an Emco PC Mill and an Emco PC Turning Center located on campus are conducted to develop the student's understanding of machining and CNC programming.

Six current experiments are briefly described below. Note how the technical topics are inter-related as the sequence of experiments is executed. This is specifically designed to help reinforce the student's understanding of processing-structure-property relationships in materials and manufacturing. Students use their materials text[6] as reference as well as handout materials from various references.

Compression Testing

The students are already familiar with tension testing from their previous Strength of Materials lab. Compression testing is a lab experience in which students see another method of determining mechanical properties of materials but without the necking instability of tension testing and, therefore, with the ability to generate stress-strain data at higher strains which would be needed in evaluating manufacturing processes such as forming. Compression testing is done on cylindrical specimens of 6061-T6 aluminum at room temperature and slow strain rates in a Tinius Olsen Super L machine with 120,000 lb capacity. A CTC technician skilled in mechanical testing operates the machine. Load and displacement data are recorded via computerized data acquisition and supplied to the students. Testing is performed using knurled dies, smooth dies, and smooth dies with Teflon lubricant to evaluate different friction levels present between the dies and the specimen. Students are required to generate true stress – true strain plots of the material response for each test, assuming constant volume deformation and no barreling. ASTM Specification E9 (*Standard Test Methods of Compression Testing of Metallic Materials at Room Temperature*[7]) is provided to the students for background information and for writing their lab reports.

Typical data and results from this lab are shown in Figure 1 which gives load vs. deflection with knurled dies and dies lubricated with sheets of Teflon and Figure 2 which shows true tress vs. true strain for the Teflon lubricated case.

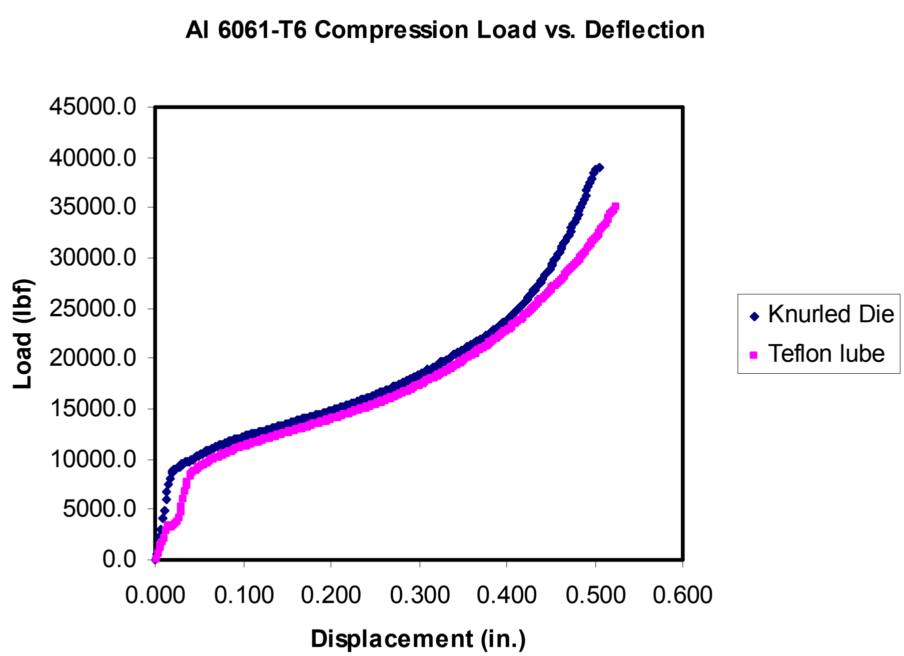

Figure 1. Load vs. Deflection for compression of Al 6061-T6 using knurled and Teflon lubricated dies

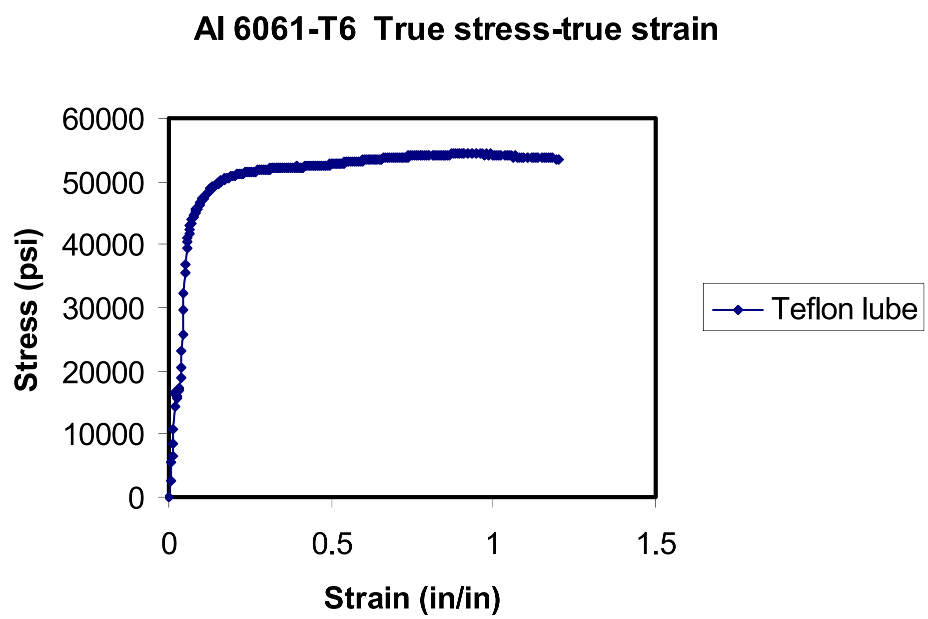

Figure 2. True stress vs. true strain from Figure 1 data (Load-deflection) for Teflon lubricated dies.

Students are required to answer the following questions in their report:

How does your value of yield strength compare to handbook reported values?
What are the advantages/disadvantages of compression tests compared to tension tests?
Does the stress-strain data follow the often-assumed relationship of
$\sigma = K\varepsilon^n$? Show your work on this.
What is the effect of friction between the work piece and the dies on the stress-strain behavior?
Are you able to determine a reasonably accurate E, Young's Modulus, with the setup used? Why or why not?

A benefit of this lab is that the technician performing the actual testing provides detailed information on what he/she is doing and why. He/she also discusses the various materials he/she has tested and some of the problems encountered in compression testing. In addition, the students are not only able to gain perspective on material behavior under compressive loading, but also gain insight on the effects of test conditions, e.g. friction, on the apparent stress-strain behavior measured.

Charpy Impact Testing

In the same lab period as the compression testing, the technician performs Charpy impact testing using a Tinius Olson Model 94 Impact Tester with computerized data gathering. Standard Charpy V-notch tests are performed on plain carbon steel at five temperatures. The students evaluate the impact data by a CVN impact energy vs. temperature plot (see Figure 3), % shear measurements and lateral expansion which demonstrates the temperature dependence of impact energy behavior as previously discussed in the Materials class. The technician demonstrates the procedure for examining fracture surfaces thus highlighting the difference between the brittle and ductile fracture surfaces.

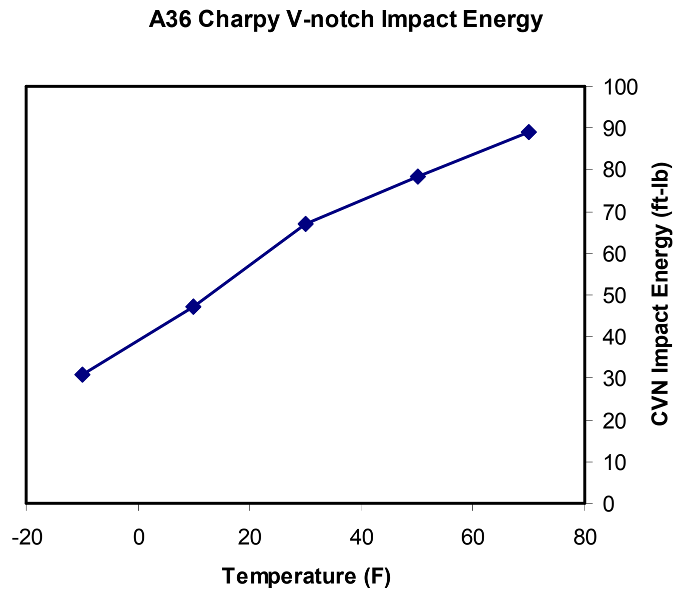

Figure 3. Charpy V-Notch impact energy as a function of temperature for A36 Hot Rolled Steel

The data in Figure 3 do not indicate the ductile to brittle transition but the technician, in this case, rather than show one upper shelf value and one lower shelf value (at liquid nitrogen temperature) as is sometimes done in the lab, decided to show a range of impact energies at "normal" environment temperatures.

Rolling

In the rolling lab, students work with an experienced technician who was a rolling equipment operator in the former steel industry in Johnstown, along with an engineer from CTC. Using a Fenn two high rolling mill, the team rolls 6061-T6 aluminum plates to various degrees of reduction using multiple passes at room temperature. Data recorded from this process consists of rpm, roll-separating forces, and torque applied to the rolls. Students make observations on the shape and dimensional changes after each pass. Handouts are given from manufacturing and metal forming references and the students are required to use these to calculate roll separation forces, roll torque, power consumed, and the coefficient of friction between the rolls and the work piece. Yield strengths as a function of induced strain are required for these calculations. The students use the true stress – true strain data they developed in the compression testing lab to determine these yield strengths, since both are performed with 6061-T6 aluminum. Comparisons can then be made between calculated and experimental values. A typical set of student data and calculated values for the rolling lab is shown in Table 1 of Appendix A.

Heat Treatment

To provide the students an acquaintance with the basics of heat treating, specimens of steel and aluminum are heat treated using various temperatures and cooling rates. Steel specimens (1018 and 1045), received as cold finished rods, are austenitized and cooled at three different cooling rates: water quench, air cool, and cool in furnace once power is turned off. This results in different microstructures as a function of cooling rate: mostly martensite for the water quench and different distributions of ferrite and pearlite for the two slower cooling rates. As received aluminum (6061) is in the T6 temper and specimens are solution treated and cooled at different rates (water quench, air cool, furnace cool). The water quench puts the material in the T4 temper, while the air and furnace cools basically overage the aluminum to differing degrees. Both the steel and aluminum specimens are then used in the hardness testing lab and in the metallography lab for further analysis.

At a session before the actual heat treatment and subsequent hardness testing, the UPJ faculty member reviews phase diagrams with special attention to the $Fe\text{-}Fe_3C$ system so the students are up to date on the type of microstructures that would be expected by the various heat treatments. Isothermal transformation diagrams are also explained and studied for each steel heat treated along with Jominy end-quench data. Students thus learn about the martensitic transformation as well as the different microstructures to be expected by slower cooling rates. Precipitation hardening is also covered in this session to prepare the students to understand the aluminum heat treatment results.

Hardness Testing

The students, using a Leco RT-240 Rockwell hardness tester, test all the steel and aluminum specimens from the heat treatment experiment. Hardness tests are also run on the "as received" specimens (the condition prior to heat treatment). The students are required to determine which Rockwell scale adequately captures meaningful differences in hardness for each type of material, ideally having all of one material type tested on a single Rockwell scale. In addition, the students are advised to test the water quenched steel using the Rockwell C scale to determine if it is actually mostly martensite (by inference as opposed to microstructural evaluation), since Jominy end-quench data are available for these steels. A typical student data set for hardness measurements for 1045 steel and 6061 aluminum is given in Table 2 of Appendix A.

While the students are performing the Rockwell hardness tests, a hands-on demonstration is given of a Vickers hardness test so the students see and experience this different type of hardness test.

Metallography

Each group of students examines two different specimens during their metallography lab. The specimens examined are those from the heat treatment lab as well as other materials, such as, Grade 2 and 8 bolts. CTC generally utilizes automated sample preparation for their own large volume work, but the students perform much of the sample preparation by hand. A CTC technician in the metallography lab instructs the students in proper sample preparation techniques for the different materials. Photomicrographs are taken of the samples at various magnifications (typically 100X and 500X) utilizing a Clemex Vision image analysis system with a Reichert metallograph. The photomicrographs are shared among all the student groups via digital images so a complete set is available to each group. Students are asked to answer the following questions in their report:

What phases are present and what is their morphology (size and shape)?
Are the microstructures what would be expected?
What is the grain size of the original material?
What are the key microstructural features (particles, inclusions, etc.)?
Identify the differences between the various cooling rates
What is the correlation between microstructure and properties?
Any other interesting observations

The various experiments described are purposely interrelated. For example, the same aluminum alloy (6061) is used in compression testing, heat treatment, rolling, metallography, and hardness testing. Similarly, the steel specimens used in heat treating are utilized in hardness testing and metallography. The main reason for this is that the students can experience and reinforce the maxim that "structure determines properties" and that the structure of a given alloy can be modified by heat treating and mechanical working. The lab report for the heat treatment, hardness testing, and metallography is done as one integrated report so students can make the connections between developing a certain microstructure, observing and categorizing that microstructure, and that microstructures mechanical strength (from hardness tests).

Summary of Benefits and Future Plans

In addition to the property-structure insights the students gain in completing the lab experiments, a significant benefit of the lab experience, due to the collaboration with CTC, is that students get to work with and under the supervision of experienced technicians in an industrial setting with the involvement of a faculty member. The technicians are well versed in the equipment they are using, have a high level of technical proficiency, and have experience and capabilities beyond the particular experiment/process being performed, which they often share with the students. Furthermore, the equipment at CTC is in general state-of-the-art; thus, the students work in a modern and changing technical environment. This allows the Mechanical Engineering Technology department at UPJ to offer lab experiences well beyond what the university could provide given the limitations of resources.

As students work on the various lab assignments with the technicians from CTC, they also are given mini-tours of other equipment and processes being developed at CTC, such as, friction stir welding, Scanning Electron Microscopy, and rapid prototyping. In addition, many samples from previous CTC projects are on display in the facility, which encourages discussion of other materials and manufacturing related topics that are not covered in the labs.

Several students each year work as interns at CTC and a relationship has developed between UPJ and CTC with graduates being hired at CTC as engineers. This aspect is of mutual importance to UPJ and CTC. It brings CTC to the students' attention as a potential employer and it provides CTC management an opportunity to further the student's educational experiences and gain insight regarding the student's potential for a successful career at CTC.

Future plans for the materials and manufacturing laboratory collaboration are basically to keep the collaboration working as effectively as it has in the past. Each year the experiments will be modified based on experience and changes in emphasis of the materials course work. This may occasionally lead to replacing an experiment with entirely new experiences, as they have in the past. For example, a laboratory experiment focused on having students generate a phase diagram is being considered. In addition, experiments focused on non-metallic materials including composites are being considered for certain aspects of the laboratory experience. But whatever the choice of experiments, UPJ and CTC personnel are committed to continuing this collaborative laboratory course that has met our respective needs so well.

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JAMES P. BANDSTRA is an Associate Professor of Mechanical Engineering Technology at the University of Pittsburgh at Johnstown. He holds a BSME from the University of Michigan, an MS from the University of Pittsburgh in mechanical engineering, and a Ph.D. from the Pennsylvania State University in Materials Science and Engineering.

RICHARD J. HENRY is Director of Advanced Manufacturing Projects at Concurrent Technologies Corporation. He holds a BS from Carnegie Mellon University in Metallurgical Engineering and an MS from Rensselaer Polytechnic Institute in Materials Science and Engineering and is a Registered Patent Agent.

Appendix A
Typical student data and calculated values

Table 1. Data and calculated values for rolling lab

	Initial	1st pass	2nd pass	3rd pass	4th pass
Height (in)	0.498	0.453	0.389	0.313	0.206
Length (in)	5.999	6.500	7.563	9.500	11.500
Width (in)	1.495	1.502	1.520	1.538	1.554
Transverse Spread (in)	-	0.007	0.025	0.043	0.059
% Reduction	-	9	14	20	34
Calculated Strain (in/in)	-	0.094	0.15	0.22	0.42
True Stress at Strain (psi)	-	44900	48900	50100	50300
Experimental Roll Separating Force (lb)		29500	44280	49020	53710
Calculated Roll Separating Force (lb)		28080	36560	42580	51640
Force % Difference		4.8	17.4	13.1	3.9
Experimental Torque (lb-in)		8280	12810	16240	17520
Calculated Torque (lb-in)		6070	9490	12050	17270
Torque % difference		26.7	26.0	25.8	1.4
Estimated coefficient of friction		0.11	0.23	0.17	0.05

Table 2. Typical Hardness testing results for 1045 Steel and 6061 Aluminum

	Water Quenched	Air Cooled	Furnace Cooled	As Received
1045 Steel HRC	**46**		**-5**	
1045 Steel HRD	**54**	**27**	**25**	**41**
6061 Aluminum HRE	**77**	**49**	**1**	**90**