

Project Based Materials Science Course

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Abstract – Albany State University’s Regents Engineering Transfer Program (2+2) allows students from rural Southwest Georgia to transfer to Georgia Institute of Technology by completing the first two years in a more supportive environment. The university started offering an introductory materials science course since 2004 as it is either a required or an elective course for all the degree programs at Georgia Tech. Since 2006 students also have to complete a team based laboratory project on developing, observing the microstructure and measure hardness of 1045 steel and the effect of heat treatment. The project allows students to develop an understanding of relationship of material properties with microstructure and how materials can be engineered to perform.

Keywords: Material science, microstructure, material properties, southwest Georgia

INTRODUCTION

Albany State University (ASU) participates in the Regents Engineering Transfer Program (RETP) which allows students from southwest Georgia to transfer to Georgia Institute of Technology, Georgia’s only public university offering four year degree program in engineering. Primarily attended by African-American students from all over Georgia with limited financial resources and average academic standing, the Engineering program at ASU has provided a unique opportunity to gain access to Engineering studies at Georgia Tech by completing the first two years in a more supportive environment. As part of the program students complete course requirements in humanities, social sciences and sciences before matriculating to Georgia Tech. They also take some of the core engineering courses required in their respective major area such as Engineering Graphics, Mechanics, Electric Circuits etc. As is mostly the case, most of the degree programs at Georgia Tech require an introductory level course in materials science either as a core or as an elective subject. In order to achieve a seamless transfer, ASU started offering “ENGR 2001 – Introduction to Engineering Materials” from spring 2004 semester thereby the first RETP institution to teach this course. Since then, this course has been accepted by Georgia Tech as equivalent to their “MSE 2001 – Principles and Application of Engineering Materials” and students completing the ENGR 2001 course with a minimum “C” grade are awarded transfer credit.

COURSE DESCRIPTION AND OUTCOMES

Primary objective of this course is to introduce students to the study of engineering materials. Building on an understanding of atomic structure and chemical bonding acquired in General Chemistry course, the course begins with the chemical and size factors determining how atoms pack together to form crystalline or non-crystalline solids. The course then introduces students to atomic diffusion, material properties, microstructural development, phase transformations and modification of microstructure due to heat treatment. Apart from metals, the observed mechanical, electrical, thermal, magnetic and chemical properties of ceramics, polymers and composite materials and their applications are also covered.

One of the major outcomes of this course is for the students to develop an understanding that the material properties are functions of structures which are influenced by processing. Thus materials can be “engineered” to achieve the desired properties. Hence material selection for a specific engineering application must include recommended processing.

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NEED FOR LABORATORY EXPERIENCE

In general the introductory Material Science course is not a pre-requisite for upper level courses and students often may not feel the need for understanding the very abstract concepts covered in the course. Though the process of material selection can be a valuable lesson for students that can be used in future in industry, without any practical work opportunity to apply the concepts taught in a traditional materials science course, students can hardly retain the concepts after the end of the semester. It was apparent to the instructors teaching Materials Science that something needs to be done to make the students participate more actively in their learning and give value to the course content. In order to make the subject matter more approachable and interesting, significant amount of work has been done around the country to introduce students to hands-on materials processing and testing by making them participate actively in laboratory projects.

Ondracek[1] in University of Nebraska – Lincoln reported virtual laboratory experiments to introduce students to real world examples contained in modules in multimedia format based on databases of test results on several standard tests for several materials. Students go through these case studies at their own pace, run tests and get an immediate feedback that encourage them to reevaluate their options till they determine the cause of the problem. Byrne[2] of Western Kentucky University developed an integrated laboratory serving both freshman level Materials and Manufacturing and sophomore level Strength of Materials courses that provide experimental experiences demonstrating the relationships between material processing and properties by data collection, organization, analysis and reporting. DeBartolo[3] and her students from Rochester Institute of Technology developed failure analysis projects as teaching tools to complement both lecture and laboratory classes. Students must identify the probable cause of failure of an object that failed in service by first analyzing the fracture surface, then by conducting sectioning, microstructural analysis, hardness testing and background research. Students are also required to present their findings before the rest of the class. Gleixner of San Jose State University and her colleagues led a NSF funded CCLI multi university project [4, 5, 6] that created Project-Based Resources for Introduction to Materials Engineering (PRIME) modules to teach the fundamental principles covered in a typical introductory materials course within the context of modern engineering technologies. Each of the modules is based on a modern technology such as Biomaterials, Alternative Energy or Sports materials that cover fundamental topics showing their interrelationship. The project is made up of Applied Engineering Content (AEC) modules and Engineering Project Lab (EPL) modules. The later consists of failure analysis, materials selection and process optimization designed along the roles played by materials engineer in modern society. Apart from teaching labs, the EPL modules include open ended projects. Skurla [7] of Baylor University found an innovative solution of overcrowding around single major equipment due to dramatic increase in enrollment by converting some lab projects to self paced independent student activity. Dubikovsky's team [8] from Purdue University developed hands-on project activity to provide students real life work experience by manufacturing, assembling and testing of parts including structural joints. Students also find out effect of heat treatment of aluminum alloys on strength and hardness.

MATERIALS SCIENCE PROJECT AT ALBANY STATE UNIVERISITY

When the Materials Science course was first introduced at Albany State University in Spring 2004, the laboratory project was not considered as traditionally it was not a requirement for this course. Subsequently it was decided to introduce a laboratory project where students can get a first hand experience in the relationship between the materials structure and their properties by conducting a team project of developing and recording the microstructure, measure hardness and how these get effected by heat treatment. However nothing could be done immediately because of lack of adequate funds to acquire expensive equipment.

Equipment

An institutional improvement grant awarded by the Department of Education under Minority Science and Engineering Improvement Program (MSEIP) in 2001 was used to establish an Engineering Laboratory consisting of a wind tunnel, a CNC lathe, a 3D Printer (rapid prototyping machine) and an universal testing machine with a brinell hardness attachment (Figure 1). Towards the conclusion of this project in December 2005 about \$20,000 of surplus fund was available that was utilized to acquire an Axiovert inverted metallurgical microscope with a Hitachi color camera (Figure 2) and software for digital capture of image along with a furnace for heat treatment. Subsequently, a

grinding / polishing machine, MetPrep 3 (Figure 3) was added in summer of 2006 and a low speed abrasive cut off saw, TechCut 4 (Figure 4), in early 2007 from student laboratory fee fund provided in the departmental budget.



Figure 1. Universal Testing Machine and Brinell hardness attachment connected to the Load Cell

The Axiovert 40 MAT inverted microscope is well suited for routine examination of samples by beginning level students. It has four position objective turret providing a range of magnification from 50 to 500. With a 3 position reflector slider the microscope is able to provide two different contrasting images, brightfield or darkfield. The MetPrep 3 Grinding/Polishing machine is ideal for low volume manual specimen preparation which can be equipped with a power head. The system allows up to 10 programmable steps including platen speed, cycle time, coolant flow etc. that are controlled by push button operation. Manual operation mode provides “one button” activation without activating the power head.



Figure 2. Axiovert 40 MAT inverted microscope



Figure 3. **MetPrep 3** 8" Grinding/Polishing machine



Figure 4. TechCut 4 Gravity fed low speed saw

Project Description

Students are introduced to the equipment and assigned the project after the mechanical properties and phase transformation have been covered in the lecture class. The entire project is done outside the scheduled class time by teams of two or three students working together. In general students spend about 4 hours to complete the project.

The procedural steps are as follows:

- (a) Prepare the specimen for viewing microstructure
- (b) View and record digital image of microstructure
- (c) Measure hardness
- (d) Conduct heat treatment
- (e) Repeat steps (a) to (c).

Specimen Preparation and Viewing

Students are assigned 1" diameter rod of 1045 steel cut to 1" section, silicon carbide papers of 240 to 1500 grit sizes, 3 micron diamond paste and 0.05 micron alumina suspension. In the beginning deep scratches left by machining are removed by filing. Then SiC papers were used in progression from low to high grit size by placing them flat on a glass surface and manually grinding the specimen surface. Water is used to cool the specimen and wash off the debris frequently. The specimen is rotated between grit sizes and checked under microscope till the markings left by previous grit size are completely gone.

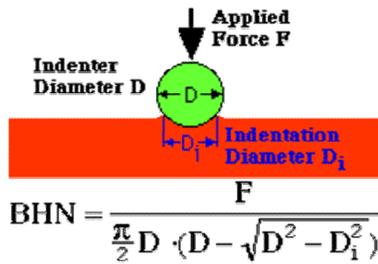
The last two steps of intermediate and final polishing were performed with the MetPrep 3 grinding/polishing machine. Intermediate polishing is done with 3 micron diamond paste on a Gold label polishing cloth and for the final polishing .05 micron alumina suspension on a Vel-Cloth is used [9]. Recommended time is 2 min for the first and 1 min for the second operation with platen speed being held at 150 RPM for both operations. The specimen is washed in methanol and kept submerged in a small beaker of methanol till the next operation.

The etching is done under a fume hood with extreme caution. Normally this operation is done by a trained student assistant wearing protective coat and acid resistant gloves at all times. The specimen is placed in 12 molar HCl for 45 seconds. The time that the specimen is allowed in contact with the acid is critical for proper exposure of the grain structure (more time will over etch the grains). The specimen is then removed with tongs and placed in a large beaker of water long enough just to neutralize the acid and then in a beaker of methanol to remove the water and any residual acid. The methanol is allowed to dry and the specimen is then immediately coated with paraffin or another oil to prevent rust.

The polished and etched specimen is placed on the Axiovert microscope and the grain structure is digitally captured by the camera after the students are satisfied with the visual image. Students normally record both brightfield and darkfield contrasting images of the micrograph with the highest magnification.

Measuring Hardness

Albany State University does not have any Brinell or Rockwell hardness tester. Instead a Brinell hardness attachment (Figure 1) is used in the Tinius Olsen universal testing machine. The removable attachment can be fixed to the load



cell during the time of the testing. A round sleeve holds the 10 mm diameter steel ball to the attachment that is brought down to the specimen under a load of 3000 kg and held for about 15 seconds and then moved up. The diameter of the resulting indentation was then measured with a vernier caliper and the brinell hardness number is calculated by the formula shown (F is in kg and diameters are in mm). Care should be taken to make the indentation away from the edge.

Heat Treatment

The specimen is placed inside the furnace when the temperature is gradually taken to about 1000⁰ C. The specimen should be held inside the furnace for around 15 minutes after the target temperature is reached to ensure stabilization of temperature. Then the sample is removed quickly with the help of tongs and quenched in a bucket of water. Thermally insulated long gloves are used for protection while removing the hot specimen. From the classroom discussion students realize the phase transformation occurring in 1045 steel, first to austenite when heated to high temperature and then to martensite when temperature is decreased suddenly.

To observe the effect of heat treatment on the specimen, it has to be ground, polished, etched again and its micrograph recorded and hardness measured as described earlier.

Results

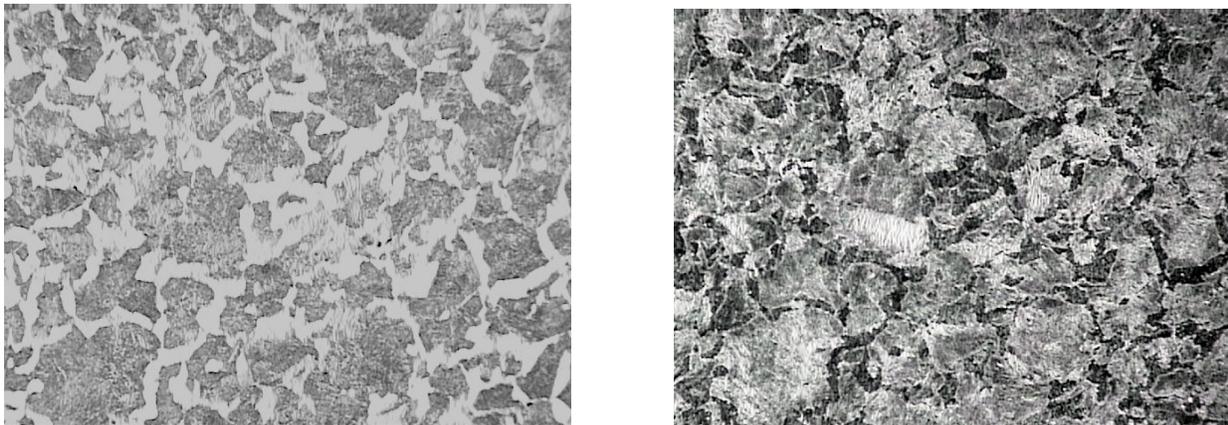
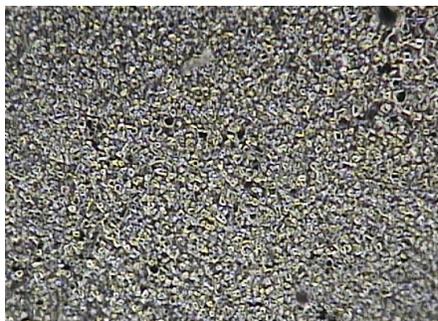


Figure 5. Brightfield and Darkfield images of 1045 steel (500X)



The micrographs shown in Figure 5 are typical of plain carbon steel. After heat treatment the microstructure normally shows denser distribution of grains (Figure 6) as expected in martensite structure. Typical hardness number increase from around 180 BHN to 400 BHN as a result of the heat treatment. Students must submit individual reports in order to earn grade for the project which account for 15% of the course grade. Report should contain a brief description of the procedural steps taken as well as problems encountered and steps taken to resolve them. Comparison of microstructure before and after heat treatment along with the change of hardness number should clearly be recorded and the formation of martensite explained in the report.

Figure 6. Darkfield image after heat treatment

LESSONS LEARNED

Albany State University's engineering program is relatively small with the freshman class consisting of 25 to 30 students. Students take the materials course in their fourth semester of study. Due to the normal attrition experienced in most engineering programs the materials course usually have only 6 to 7 students in the class completing the course. In general there is only 3 student teams work on the project each year under the supervision of a student assistant who had successfully completed the course before. Students decide their own schedule in the lab in consultation with the student assistant. Because of such small class size, a formal course evaluation was never conducted. In private, students have expressed satisfaction about their achievement in developing the microstructures and realization that the structure and property are interrelated. However, they also expressed unhappiness about the stringent grading of their formal lab report and expected to be compensated with a higher percentage of final course grade coming out of the lab project.

CONCLUSION AND FUTURE PLAN

The project has proved successful not only in allowing students to be confident in using the equipment and software, but more importantly they can relate to the interconnection of material structure and its properties and how the material can be "designed" by applying suitable process in order to have the desired properties for specific application. However, it may be hard to justify additional time and effort needed for both the students and instructor for this evolving experimental project under the present structure of a 3 credit lecture course. A more permanent solution may be to increase the course credit hours from 3 to 4, the extra hour being used in the laboratory class. The project can then be expanded to include measurement of other mechanical properties such as modulus, yield stress and ultimate strength as outlined in the work of Schneider [10] of Mississippi State University. Available equipment can be used for this purpose, such as CNC lathe to machine a test specimen to be used in the universal testing machine. It will be desirable to work with a non-ferrous material such as aluminum because of the limitation of our equipment. The only limiting factor of adopting such a plan will be funds to hire a laboratory assistant to cover the additional duties as availability of qualified student assistants cannot be counted on.

REFERENCES

- [1] Ondracek, R.P., *Multimedia Virtual Laboratories for Introductory Materials Sciences Course*, 1999 ASEE Annual Conference, Charlotte, NC.
- [2] Byrne, C., *Integrated Materials Science Lab Experiences in a Mechanical Engineering Curriculum*, 2005 ASEE Annual Conference, Portland, OR.
- [3] DeBartolo, E., et al, *Failure Analysis Projects as Teaching Tools in Materials Science*, 2006 ASEE Annual Conference, Chicago, IL.
- [4] Gleixner, S., et al, *Development of Project-Based Introductory Materials Engineering Modules*, 2005 ASEE Annual Conference, Portland, OR.
- [5] Gleixner, S., et al, *Project-Based Introductory to Materials Engineering Modules on Biomaterials, Solid Oxide Fuel Cells, Non-Volatile Memory, and Fiber Reinforced Plastics*, 2006 ASEE Annual Conference, Chicago, IL
- [6] Gleixner, S., et al, *PRIME MODULES: Teaching Introduction to Materials Engineering in the Context of Modern Technologies*, 2007 ASEE Annual Conference, Honolulu, HI.
- [7] Dubikovskiy, S., *Practical Skill Development, analysis and testing are used to teach the topic of Heat Treatment of Aerospace Aluminum Alloys*, 2007 ASEE Annual Conference, Honolulu, HI.
- [8] Skurla, C., *Self-Paced Laboratory Modules for Engineering Materials and Manufacturing Processes Laboratory Course*, 2007 ASEE Annual Conference, Honolulu, HI.

- [9] Osmanzai, O. and Redden, B., *Applications Report – Low-Medium Carbon Steel*, Allied High Tech Products, Inc., Rancho Dominguez, California.
- [10] Schneider, J., *Integrating Materials Science into the Mechanical Engineering Curriculum*, 2006 ASEE Southeast Section Conference.

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Atin Sinha received his Ph.D. from the University of Tennessee Space Institute in Aerospace Engineering in 1984 and worked in Learjet and Honeywell before moving to academia. He joined the Albany State University in 1999 as coordinator of the transfer engineering program and teaches freshman and sophomore level courses in engineering. His current research interest is rapid prototyping and reverse engineering. He is also engaged in motivating students in inquiry based learning in engineering problem solving through laboratory experimentations.