AC 2009-900: TESTING COMMERCIAL-GRAGE THREADED FASTENERS AS A CULMINATING LABORATORY PROJECT IN MATERIAL SCIENCE FOR THE ENGINEERING TECHNOLOGY CURRICULUM

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Abstract

The major emphasis of a material science course is to provide the student with a broad level of information on different industrial materials. In our institution, working on a quarter system, this course becomes very aggressive and challenging in the amount of information that is presented to the students. In addition, the course involves time in the laboratory learning different practices used to obtain various properties of these materials. This leaves very little time to require the students to apply their knowledge to perform any kind of detailed analysis. In light of this, the authors proposed a new and final laboratory project that required the students to synthesize the overall course outcomes to conduct a thorough analysis of a commercial threaded fastener, widely used in household and industrial applications. As with most screws and bolts purchased from typical commercial stores (such as Wal-Mart, K-Mart, Target, etc.) size is the only information provided. The mechanical properties and even the material they are made from are usually not given. During this project students analyze one of these commercial fasteners and begin by listing different physical properties. The students are asked to sketch the expected shape of the stress-strain diagram for the material they suspect it is made from. Students will also speculate on the ultimate force that the fastener will be able to withstand. A bracket was manufactured so that the students can then place the fastener in a tensile tester and use it to determine the mechanical properties. Once the students obtain the stress-strain diagram they will compare the experimental response with their guessed result. In addition, multiple tests are done and the variation in maximum tensile force can also be examined. The students will also generate micrograph pictures of the fasteners to help them understand the chemical properties of the fastener material. Using all of this information the students must then be able to identify the base material used to make the fastener and any material treatments it may have gone through. This has turned out to be a great experience in showing the student how to use the knowledge they have gained to analyze an engineering component. The purpose of this paper is to explain the details of this laboratory project as well as discussing the educational results obtained by including this new project in our material science curriculum.

Background

One of the challenges in education today is trying to bridge the gap between students who often view education as an effort to try and push as many important facts into their brains as possible versus the understanding that we as educators have that students need to be able to synthesize that knowledge and be able to use it to make decisions (what we often call Design). Certainly, many courses that students take early in their program emphasize the learning of information and tools that are necessary foundations to making good engineering decisions. We all want our students to be able to create and design, but the questions of when and how (and sometimes how much) make the issue of introducing students to design less than straightforward. Of course, all of this is merely a discussion of an idea presented in 1956 by Benjamin Bloom in his Taxonomy. Bloom identified three types of learning, one of which is the cognitive domain.
Within his cognitive domain he identified six levels that most educators think of when referring to Bloom’s Taxonomy. As a quick review, the six levels of Bloom’s cognitive domain are presented in Figure 1.0 below.

Figure 1.0, Bloom’s Taxonomy of Cognitive Learning

Educators are very familiar with the concept presented in Bloom’s Taxonomy. The idea that students can learn at different levels is a driving force in how educators develop and construct their lessons. We know that students can learn at a lower level where all they are able to do is recognize the material; at a higher level they can repeat back what they have learned but at the highest levels they are able to synthesize their knowledge to analyze and draw conclusions. It is unfortunate, but when we find ourselves pressed for time and feel that we have more material to cover than we can get to there is a temptation to move down the scale of the Taxonomy and give large amounts of information to the students in hopes that, as a minimum, they will at least be able to memorize it and repeat it back. We all know that we aspire to help students to reach the highest level which of course requires the greatest understanding of the topics and ideas.

As a simplification in teaching engineering technology the six levels can be collapsed into a three stage process that somewhat mimics the progression students go through in higher education: First we teach them how to Calculate; Second we teach them how to Analyze; and Third we teach them how to Design. Having only three levels is easier to remember and use in creating course materials.
Program classes in the freshman and sophomore years often emphasize the Calculate aspect as the students are still building their foundation of knowledge and tools. Senior level courses should be emphasizing the aspect of Design and decision making to prepare them for this final level before they graduate. In the middle is an often overlooked aspect that bridges the gap between Calculate and Design and that is Analysis. If students can become effective in analyzing an existing design they will improve their own design skills. It is this skill that we set out to emphasize in a junior level materials class at our institution.

Students and faculty are familiar with the Calculate level of education as it has been a very prevalent method throughout the years. It is also very comfortable for both student and educator. In fact, reports have shown that students have come to expect this type of teaching and when methods are used that differ from this they often think that the teacher isn’t teaching and that they are not learning. Because of this level of comfort and the fact that the amount of knowledge required of students in technology has vastly increased, there is a temptation to fall back into this level in an effort to get as much information to students as possible. Evidence of this comes from teaching a junior level materials course. The course runs over a single quarter. It consists of both a lecture and laboratory work. There is already more material to cover than is allotted for in the class and yet the hope is to add additional information on composite materials to the
lecture. In addition, many of the students have not yet had course work in technical writing so elements of how to write a successful lab report is also included in the course material. As the amount of material and laboratory skills seemed too much for the time allotted there was a fear that the course was becoming too focused on providing the students with vast amounts of knowledge but expecting the students to piece together for themselves how they would ultimately use this knowledge. In addition to the overload in lecture material, the laboratory experience was going to increase as well. The students get exposed to all of the standard material testing procedures including tensile testing, hardness testing, heat treating and the process of mounting, polishing and etching samples to view them under a metallograph. We were also getting ready to try and add-in some laboratory work using non-destructive testing methods and some work with composites. After awhile it became apparent that the students were becoming very adept at performing the various, separate tasks of material analysis, but something was needed that would synthesize everything that they had learned into a practical exercise and possibly help me assess their abilities to use that information. The idea came to fruition when one of the department’s professors acquired a new ceiling fan.

Introduction

One day his wife came home with a new ceiling fan that she wanted installed in the master bedroom. The location of the fixture was directly over the bed. Consequently he wanted to be very sure that this fixture was going to remain firmly attached to the ceiling. During the installation process it became apparent that this fan was significantly heavier than the fixture it replaced. It caused the professor to wonder if the two machine screws that mounted the fan to the house were sufficient to carry such a heavy load. Typical of most components supplied with the fan, there were no specifications for the threaded fasteners that would allow any determination as to how much weight they would be able to hold or even indicated what material they were made from. It was realized that this was exactly the type of question the students ought to be able to answer if they truly met the objectives for the materials course. The machine screws used by the light fixture were standard #10-24 and consequently, some identical screws were acquired for the students to use in the laboratory. The machine screws used in the lab were purchased right off the shelf from the local Wal-Mart.

Material Properties

To fully understand the laboratory process that the students would be using requires a quick review of how the material for the course is presented. Since the students will be studying a number of different materials throughout the course it is important that they begin with a framework to help them process and understand all of this information. The framework consists of dividing each material’s properties into three different categories: Physical Properties, Chemical Properties, and Mechanical Properties as outlined in their textbook. The following table briefly outlines the significant characteristics of each of these three types of properties as found in the text, Applied Strength of Materials, by Robert A. Mott.
Table 1.0, Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Definition</th>
<th>Significant Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>Pertains to the science of physics. Can often be obtained by observation.</td>
<td>Thermal Conductivity, Thermal expansion, Electrical properties, Ferromagnetism, Magnetic Hysteresis, Density, Porosity</td>
</tr>
<tr>
<td>Chemical</td>
<td>Is usually measured in a chemical laboratory and cannot be determined by visual observation.</td>
<td>Composition, Microstructure, Crystal Structure, Corrosion Resistance</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Pertains to the characteristics of a material that are displayed when a force is applied to the material. This property often requires the destruction of the material for measurement.</td>
<td>Yield Strength, Ultimate Strength (Tensile strength), Hardness, Modulus of Elasticity, Poisson’s Ratio, Percent Elongation, Ductility, Capacity to Work Harden, Resilience, Toughness, Yield Strength in Shear, Mohs hardness test, Brinell hardness test, Rockwell hardness test, Impact strength, Endurance limit, Creep</td>
</tr>
</tbody>
</table>

As mentioned previously, the intent of the lab exercise was to engage the students and require them to use what they had learned in the course to analyze these machine screws. They were expected to determine how these machine screws would perform while holding the heavy ceiling fan over the bed.

The Laboratory Exercise

To conduct this laboratory exercise each student is given a copy of the lab handout during the lecture portion of the class. A copy of this handout can be viewed in the Appendix to this paper. The students are expected to read through it and be ready when they show up for their lab experience. The lab presents the open-ended question asking the students what load these machine screws will be able to handle by way of presenting the ceiling fan scenario. However, since the students are still often a little apprehensive about applying what they have just learned in the class, the laboratory is written as a guided exercise. It asks the students to analyze the machine screws by determining each of the three categories of material properties as found in Table 1.0 above. First the students will evaluate the Physical properties of the machine screws. This can be seen in the first question on the student lab handout. The students are given a sample screw to examine and are asked to write down as many physical properties as they can. Since ferromagnetism is a physical property a magnet is available but isn’t offered up unless a student thinks of checking for this property and asks if a magnet is available. Possible physical
properties that the students should be able to come up with during this step relate to the color, the thermal properties ("feels cold"), mass/density comments, etc.

As is often the case when introducing a new exercise, students can think of answers that you hadn’t even considered. While one student team was performing this exercise, one of the students accidentally dropped the screw. The floor of the materials laboratory is concrete and the metal screw made a bell-like sound as it bounced off the floor. The student rightly perceived that the sound the material made was also a physical property of the material and could possibly give some incite into what type of material the screw was made from. This student correctly perceived that sound and acoustics can be an important material property. The course introduces one such example to students by discussing the sound dampening characteristics of gray cast iron. Another example that came to my mind is the old craftsman technique of tapping wooden hammershafts during the piano manufacturing process and using the sound to determine quality and the best location within the piano action. Also, debate continues on if the quality of the sound made by a brass instrument relates in any way to how the instrument sounds when the bell of the instrument is flicked with your finger. After the students write down the observed physical properties they then discuss them within the group and arrive at a consensus for their team’s list of properties.

The next step is to discuss the Chemical Properties. As previously given in the table, these properties are not easily obtained by observation and require some laboratory work to acquire. Because of the time constraint, a sample of the machine screw was already prepared by mounting it in Bakelite®, polishing it and etching it. The sample is provided to the students and they are allowed to view the microstructure through the metallograph. The students are then asked to write down their observations and are then required to discuss this as a group and create a team list of Chemical properties. In a previous lab the students have gone through the procedures of mounting, polishing, etching and viewing some samples of plain carbon steels and a chromolly steel. An ASM handbook of Metallography and Microstructures of Ferrous Alloys is provided to the students to assist them in making some type of determination of what material they are looking at through the metallograph. A space is provided for the students to sketch significant characteristics of the microstructure of the machine screw. Throughout this process the team is engaged in discussion as to what they are looking for and what they are able to view.
Finally the students get ready to obtain some Mechanical Properties of the machine screw. Of course one of the characteristics of a mechanical property is that destruction of the part is often necessary to obtain this category of properties. That makes these properties the most fun to obtain but it also makes the students more inclined to jump right to mechanical testing before considering the other important properties of the material. Hopefully by now the lab has shown them the importance of working through each property in turn to guide their analysis.

At the beginning of the course the students performed a laboratory test using the tensile testing machine. They are now able to perform a tensile test on the machine screw and use what they learned from that previous experience. Because of their past lab experience, they are given minimal instruction on what they need to do in order to correctly perform the tensile test. In order to mount the screw in the tensile tester some brackets were manufactured. The brackets consist of two pieces of square iron with appropriate holes drilled in the top and bottom. One hole is sized to accommodate the mounting bolt for the tensile tester and the other one is sized to accommodate the machine screw. A picture of these brackets mounted in the tensile tester with a machine screw is shown below.

Figure 3.0, Micrograph of the Threaded Fastener material
Figure 4.0, The brackets and a threaded fastener mounted in the tensile tester.
Before the tensile test is performed the students need to calculate the correct tensile area. Hopefully the students remember how to do this for a threaded fastener, but in order to help them get correct data, the formula is repeated in the lab handout.

Also, before the students perform the tensile test they are required to sketch the shape of the stress-strain diagram that they expect to get from the test in their student laboratory handout. Requiring students to make a decision as to what they expect gives them a basis for comparison and enhances the learning experience. The students have looked at numerous examples of typical ductile material stress-strain diagrams from their textbook. In addition, the students have previously performed this test in the lab with an aluminum sample that gives a stress-strain diagram (actually force-elongation from the equipment until converted to values of stress and strain) that looks like the figure below.
Consequently, when the students sketch what they expect from the tensile test of the machine screw they will sketch something similar to this shape. One other item that makes the lab fun is getting each student to make a guess prior to the tensile test as to the maximum force that they think the bolt will reach in tension before failing. Granted this is more of a gamble than an educated guess but it makes the experience a little more enjoyable. One of the best learning moments from this lab is when the tensile test is performed and they obtain a diagram that looks like this:
Because this diagram looks significantly different from what they are expecting it generates very productive discussions to explain the difference. Now that they have the diagram from the tensile tester they can calculate the important numbers for this material: yield stress, ultimate stress, and modulus of elasticity. The students can compare these numbers with tabulated material data. Now that the students have all of these properties of the material they can make an educated guess as to what material the screws were made from, what possible hardening process it went through, and, ultimately, they can answer the original question: “Should I be concerned about the large ceiling fan hanging over my bed?”

Methodology

The following flowchart summarizes the steps in performing the laboratory exercise.
Initial Problem Statement:
“What material is the fastener made from & Will it successfully hold the ceiling fan?”

Analyze Physical Properties of material
Possible observations:
- ferromagnetism
- color
- density
Discuss and draw conclusions based on Physical Properties

Analyze Chemical Properties of material
Prepare or obtain prepared sample:
- Observe through metallograph
- Compare with Handbook of material micrographs
Discuss and draw conclusions based on Chemical Properties

Analyze Mechanical Properties of material
Prepare a sample for a hardness test:
- Perform test if sample is large enough
Prepare sample for tensile test:
- Calculate tensile area for a threaded fastener
- Sketch expected shape of stress-strain curve
- Perform the tensile test
Discuss and draw conclusions based on Mechanical Properties

Final analysis
Use all of the preceding information to make a final educated guess about the material and its ability to withstand the weight of the ceiling fan. Discuss any limits to the method and what implications this may have upon the final material selection.

Figure 8.0, Flowchart of Laboratory Methodology.
Lessons Learned

When the students were presented with the overall problem statement (can the bolt handle the load) they were a bit hesitant in how to provide the answer. Stepping through the lab experience opened many of their eyes by showing them that they know more than they think they do and that they have the tools for a systematic analysis of the material. It was also a nice benefit that the machine screws used in the lab were relatively inexpensive so if mistakes were made during the tensile test another sample could be provided allowing the students to learn from their mistakes. One other comment, the brackets used for testing the screws were originally manufactured to do some testing during an ASME mini-course held on our campus on the topic of the bolted joint. While doing tests for this class it became apparent that one possible mode of failure for these screws was to have the internal threads on the nuts strip out because the nuts supplied were very thin. Since this type of failure doesn’t allow the students to use their full knowledge of mechanical properties the decision was made to double-nut the screws when mounted in the tester. This eliminated that problem but does eliminate one of the possible failure modes for the mounting of the ceiling fan. It is worthwhile to point this out to the students.

Also, all the data from the different lab teams was gathered so that the students could then do a small statistical analysis on the maximum force the screws were able to hold. One of the best parts of this lab is that the instructor doesn’t have the answer. When the students ask if they “got the right answer,” the question can simply be turned back on them. It shows them that they need to have confidence in their methods.

The lab as presented above would work for any material taken from some mechanical part. If there is time at the end of the lab experience additional information specific to threaded fasteners is covered. This includes discussing with the students what possible manufacturing method was used to make the threaded fastener. During this discussion of the possible methods for doing this (cut threads, molded threads, rolled threads) students are encouraged to use the macro-stand to take a close view of the head of the threaded fastener as shown below. This allows the students to see that the outer diameter of the threads is actually larger than the small portion of the shaft under the head that isn’t threaded. This should help them figure out that these threads were rolled onto the shaft. Then a discussion ensues as to how this type of manufacturing process would affect the properties of the material the fastener is made from. In addition the students can go back to the metallograph machine and look at a portion of a fastener that is cut lengthwise. This allows them to view the thread edge-on and they can see the evidence of the coldwork that took place during the thread-forming process. Since this discussion is a bit of a side topic to the main question asked at the beginning of the lab, it is saved for the end to fill any unused time.

This lab is successful because it starts with the simple question of asking the students whether or not this machine screw will safely hold my ceiling fan. Then, it provides guidance to show them how to use what they have learned in the class in an ordered and scientific analysis of the material. This lab is based on an actual part that has a connection with real life. Many of us have had a school experience where we were given a sample to identify that was cut from some
½ inch round stock. The process was fun and challenging but there was no connection between the material we were testing and how it might actually be used to make something.

Figure 8.0, Close-up view of the head of the threaded fastener.
Figure 9.0, Micrograph of the root of the thread showing how the manufacturing process affects the material.

Conclusions

First, this lab was very effective in highlighting to the students and instructor a weakness they had in being able to utilize the skills they had learned in this course to start from scratch and successfully analyze a given material. This lab experience was also successful in helping the students synthesize all of the various material testing methods they have practiced into a cohesive testing methodology and process. This lab also successfully generates meaningful discussions based on the fact that the students get results from the tensile test that are completely different than what they expect.

Bibliography

1. Taken from http://en.wikipedia.org, on Bloom’s Taxonomy.


TECH 353
LABORATORY #8
Testing of Threaded Fasteners

Week of June 2\textsuperscript{nd}

NOTE: This lab requires each student to bring a pen/pencil, Textbook, and Calculator to the lab.

Submitted by:
Introduction: Not too long ago my wife bought a large ceiling fan that she wanted installed in our master bedroom. During the process of installing it I noticed that it was quite heavy. Knowing that this large, heavy fixture would be hanging directly over my bed I wanted to be sure that the two machine screws provided with the fan would be sufficient to hold it up. I searched everywhere but couldn’t find any information on what load these screws were rated for. I went to the store and found a package of similar-sized screws but couldn’t find any additional information that would tell me what load they could handle or even what material they were made from. In this lab we will use all of the knowledge that we have gained throughout the course on material properties to draw some conclusions about some threaded fasteners that are identical to the ones holding up my ceiling fan. The fasteners we will be using are some #10 machine screws purchased from Wal-Mart.

Step 1: The first step in the lab is to make some educated guesses about the material these are made from based on the Physical properties that you are able to observe. Look at the fasteners, hold them in your hand, hold them up to a magnet then take a few minutes to write down your observations and conclusions below:

Step 2: The next step involves obtaining the Chemical properties of the machine screws. Due to time limitations one of the machine screws has already been sectioned, mounted in Bakelite©, polished and etched. Use the metallograph to observe the microstructure of the material and sketch some of the significant features in the area below.
Based on your observations, what can you tell about the material of the screws now?

**Step 3:** The next step in examining these machine screws is to conduct a tensile test to obtain some mechanical properties. Before the test is conducted sketch what the shape of the curve should look like based on what you observed in Steps 1 & 2:

**Step 4:** Now perform the tensile test. Did the shape of the resulting graph match what you sketched in Step 3? What was different? How do you explain any differences? Now use the results from the test to answer the following questions:

- At what force did the material begin to yield? ________________
- What was the maximum force obtained by the screw? ________

**Step 5:** Now convert the two forces above into stresses. Remember that in order to do this you need to divide by the cross-section area. For a threaded fastener it is not as easy as just using the diameter and calculating the area of the circle because the shaft of the threaded fastener has had
threads cut into it. A conservative method would be to use the minimum diameter where the 
threads cut in deepest, but since the cut spirals down the shaft and doesn’t make a complete 
circle around the shaft then this method would not be as accurate. In the Strength of Materials 
class you will learn or have learned that the formula to calculate the Tensile Stress Area of a 
threaded fastener is:

\[
A_t = 0.7854 \left( D - \frac{0.9743}{n} \right)^2
\]

Where \( D \) is the major diameter in inches and \( n \) is the number of threads per inch. For the #10 
machine screw you can look in standard tables to find that it has a major diameter of 0.1900 
inches and 24 threads per inch. Use the space below to calculate the Tensile Stress Area of the 
#10 threaded fastener:

\[
A_t = \frac{D}{n}
\]

Now divide each of the forces in Step 3 above by this area to obtain the following stresses (don’t 
forget to put units next to the numbers):

Yield Stress = 

Ultimate Stress = 

**Step 6:** Now compare the values for Yield Stress and Ultimate (Tensile) Stress with values in 
the back of the book. Also pay attention to the shape of the diagram created by the tensile tester. 
What material do you think that this machine screw is made from and why? What, if any, 
treatments have been done to the material and what led you to make this conclusion?