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Utilizing material comparisons as an inexpensive and engaging culminating laboratory experiment

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Utilizing material comparisons as an inexpensive and engaging culminating laboratory activity

Lessa Grunenfelder

Abstract

Laboratory courses in the mechanical behavior of materials expose students to a variety of material types and experimental methods. Although experiments are often designed to ascertain specific material properties using standardized specimens and procedures, students may struggle to translate those discrete measurements into the broader context of engineering design and material selection decisions. In this short writeup (intended for presentation in the “activities with impact: experiments!” session) a culminating activity developed for an introductory materials laboratory course is described. The activity, performed during the final week of the semester, tasks students with revisiting materials tested throughout the course and considering them in a broader context. Students measure density to calculate specific stiffness and strength and qualitatively assess durability through observation of passive corrosion. Results of this investigation, combined with cost and other practical considerations, are used to make and justify material selection decisions. The activity, which has been run for several semesters, is engaging to students while providing an overarching course takeaway, linking laboratory exercises and lecture content to real-world engineering applications.

Motivation

MASC 310L: Material Behavior and Processing is an undergraduate laboratory course at the University of Southern California (USC). Although USC does not have an undergraduate materials science major, MASC 310L is a required course for aerospace and mechanical engineering students and is taken as a technical elective by students in other engineering disciplines. For many students this single-semester laboratory course represents their primary exposure to the mechanical behavior, properties, and processing of engineering materials. Consequently, it is essential that the course and its associated laboratory experiences are both informative and engaging, leaving students with a positive impression of the field of materials engineering.

Instructional laboratories are a central component of engineering education. While laboratory courses serve multiple functions, researchers, students, and instructors alike consistently identify a key role: connecting theoretical concepts to real-world application [1–3]. In his master’s thesis at the University of Calgary, Mackinley Love investigated student and employer perceptions of undergraduate engineering laboratory experiences [4]. The study was motivated by recurring student feedback indicating a perceived disconnect between laboratory activities, lecture content, and future career relevance. Coding of open-ended survey responses from students taking a laboratory class similar in scope to MASC 310L revealed that students primarily associate the career value of laboratory courses with the acquisition of “hard skills” and industry-specific technical knowledge [4]. Student motivation, therefore, is adversely affected when laboratory activities are not seen as directly relevant to future coursework or career goals.

While the development of technical skills is undeniably necessary, the laboratory environment also provides an excellent opportunity for cultivating professional, or "soft" skills. In Love's thesis work, managers at an engineering company in the materials sector were surveyed alongside students [4]. Both groups placed high value on teamwork, collaboration, and communication skills [4]. These findings suggest that laboratory activities should integrate teamwork, hands-on experimentation, real-world relevance, and industry-oriented technical communication. The "material comparisons" activity developed for MASC 310L does just that, while being straightforward and low-cost. The activity, described in the following sections, could be readily adapted by other faculty to support a range of instructional objectives.

Course Information

MASC 310L is offered during both the fall and spring semesters, with a typical enrollment of approximately 80 students per semester divided into two lecture sections. Students across both lectures are split into multiple laboratory sections, with each section accommodating a maximum of 16 students. Recognizing the pedagogical importance of constructive alignment [5] the course has been intentionally designed such that laboratory experiments and assessments are directly tied to lecture topics and course learning objectives. Lecture sections meet either on Mondays and Wednesdays or on Tuesdays and Thursdays, while laboratory sections are held throughout the week. To ensure synergy between lecture and laboratory content, experiments are scheduled to occur approximately one week after the necessary background material is introduced in lecture. Because of university holidays, laboratory sections do not meet during four weeks of each 15-week semester. Although the specific dates vary between the fall and spring terms, a general outline of course topics and corresponding experiments is presented in table 1. The focus of this writeup is the "material comparisons" lab that takes place in week 15 (bolded in table 1).

Table 1. Schedule of lecture topics and laboratory experiments in MASC 310L

Week	Lecture Topic	Lab
1	Classification of materials, stress and strain	No lab
2	Tensile properties	Intro and safety, data presentation tips
3	Stress strain curves, hardness, atomic bonding	Tensile and shear testing of metals
4	Atomic structure of materials	Vicker's hardness of metals
5	Plastic deformation and dislocations	Tensile behavior of polymers
6	Strengthening mechanisms	No lab
7	Annealing	Rolling and Vicker's on cold worked samples
8	Intro to phase diagrams	Annealing and tensile testing of cold worked and annealed metals
9	Phase diagrams	No lab
10	Phase transformations	Phase diagrams
11	Hybrid materials – composites	Heat treatment of steel
12	Manufacturing	Fabrication of composites
13	Failure (fracture and fatigue)	Bend testing of composites
14	Creep and durability	No lab
15	Materials and the environment	**Material comparisons**

Across the laboratory activities listed in Table 1 students investigate a range of engineering materials using a variety of experimental techniques. Details of the test samples and experimental methods employed in the MASC 310L labs are provided in an appendix. In the penultimate week of the term students are introduced to material durability in lecture, with an emphasis on oxidation and corrosion. The final week of lecture presents a big picture view of the materials lifecycle and the impact of material selection on the environmental impact of products and structures. The material comparisons laboratory was designed to align with these topics and provide a similarly integrative big picture takeaway to the laboratory component of the course. In the activity students revisit 6 materials they have tested previously in the semester (brass, aluminum, steel, acrylic, polyethylene, and carbon fiber reinforced epoxy composite). The general flow of the activity is shown in the schematic in Figure 1, with additional details provided in the following sections.

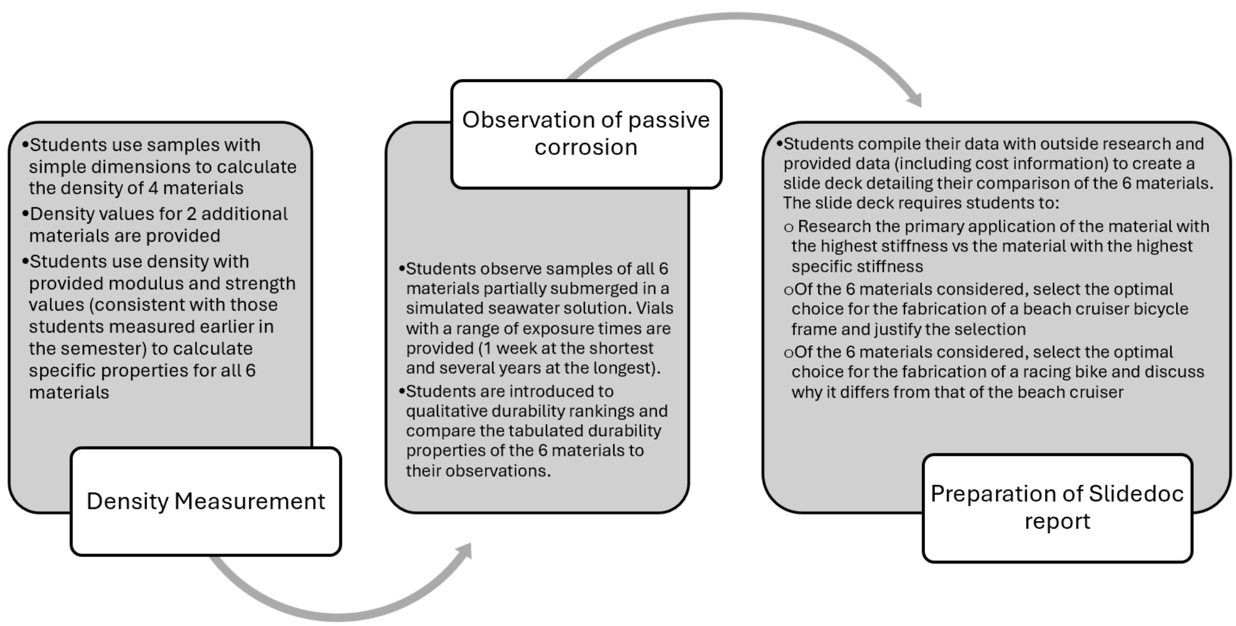

Figure 1. Overview of the material comparisons activity. The entire process, including preparing and submitting the slide deck report, takes place within a single 2-hr. lab session

Measurement and Observation

The material comparisons lab tasks students with extending their analysis of several engineering materials to include attributes beyond mechanical properties. Density (and stiffness-to-weight and strength-to-weight ratios), corrosion resistance, and cost are emphasized. Students begin by independently measuring the densities of 4 materials: aluminum, brass, steel, and acrylic. Four lab stations, each of which accommodates four students, are supplied with multiple samples of each material and the necessary measuring equipment. To simplify density measurements through volume determination, samples are provided in basic shapes: 1 in^3 cubes of aluminum and brass, rectangular prisms of acrylic in various sizes, and machined lengths of 1/8 in thick steel bar stock (see Figure 2). Students use rulers and calipers to measure dimensions and small balances to determine weight. After collecting individual measurements, students combine their data with values calculated by others at their lab station to report a density range for each material.

To complement the four student-measured densities, density values are provided for two additional materials - polyethylene and a carbon fiber reinforced epoxy composite. These values are supplied rather than measured because density determination is straightforward, making testing six different samples unnecessary. Additionally, samples of the final two materials with simple geometries were not readily available when the activity was developed.

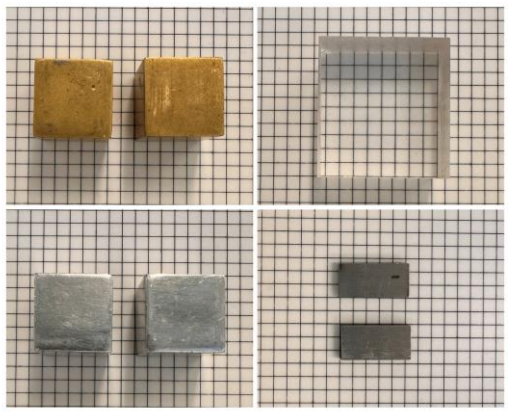

Figure 2. Material samples used for density measurements. From top left to bottom right: brass cubes, acrylic blocks, aluminum cubes, steel bar stock. Images are presented on a 5 mm × 5 mm grid for scale.

At a central lab table samples of all six materials of interest (brass, aluminum, steel, acrylic, polyethylene, and carbon fiber reinforced epoxy) are provided for observation of passive corrosion. The corrosion samples have the dimension and form students are familiar with from mechanical testing performed earlier in the course (see Appendix). Each semester, a simulated seawater solution is prepared one week prior to the comparisons activity. To prepare the solution 7 g of salt is measured and tap water is added until the total mass reaches 200 g, yielding a salinity in the 33–37 g/L range typically found in seawater [6]. Tap water is used because it contains magnesium, calcium, and other minerals naturally present in seawater. The solution is distributed into multiple vials such that each contains a partially submerged sample of a single material. Vials prepared in the current semester, as well as those from previous semesters, are available for student observation, allowing students to examine the effects of both short-term and long-term exposure to a potentially corrosive environment.

Figure 3. Left: students at a lab station calculating the densities of provided samples.
Right: Passive corrosion samples for student observation.

Analysis and Report Preparation

In addition to performing measurements and making observations, a goal of the material comparisons activity is to guide students through the process of applying and presenting their results. Professional engineers are reported to spend 20-40% of their workday engaged in some form of scientific communication [7], yet formal report writing likely constitutes only a small fraction of the resulting work product. Jeter and Donnell have classified the types of reports typically prepared in undergraduate engineering courses as itemized reports, extended abstracts, short narrative reports, and longer narrative reports [8]. Across these classifications report formats vary widely and include not just written reports but memos, posters, oral presentations, technical notes, and other artifacts [9].

In professional practice, short documents such as memos and slide decks are increasingly common, both for internal reporting and for communicating results to clients. Slide decks, dubbed "Slidedocs" by Duarte [10], are a particularly effective form of communication that combines text and visuals into efficient, information-dense packaging. Creating an effective Slidedoc, however, is a skill that is not commonly taught to undergraduate engineering students. While PowerPoint and similar software packages are designed support oral presentations, a Slidedoc is intended to be read independently by the recipient and therefore requires more detailed content and intentional formatting [11,12]. A well designed Slidedoc addresses one main idea per slide [10]. The modular structure makes Slidedocs not only effective for delivering information, but also valuable as a reference tool.

To expose students to this increasingly common form of professional communication, selected laboratory experiments in MASC 310L are accompanied by Slidedoc assignments. Because students are new to the format a PowerPoint template is provided (all USC students have free access to PowerPoint and other Microsoft office products). The template contains a fixed number of slides, each with a clear and specific title. Students are instructed not to add or remove slides. The template itself is used to provide instructions and students edit each slide to create a finalized Slidedoc. For the materials comparison laboratory both the hands-on activities and the Slidedoc template were designed to allow students to complete all measurements, observations, and documentation within a single two-hour lab period. Students work in groups of four and submit one Slidedoc per group. The lab occurs during the final week of the semester, with the final exam period beginning midweek the following week. When students submit their Slidedoc at the end of their lab session no additional analysis or submission is required, allowing students to focus on preparation for final exams.

The Slidedoc template for the material comparisons lab begins with a partially completed data table that students populate with information (see Figure 4). In addition to reporting the density values measured in the lab, students use mechanical property values (taken from a material property database [13], but consistent with properties tested by the students earlier in the semester) to calculate the specific stiffness and specific tensile strength of each material. Through this process students are introduced to the concept of specific properties and their importance in weight-critical design and transportation applications.

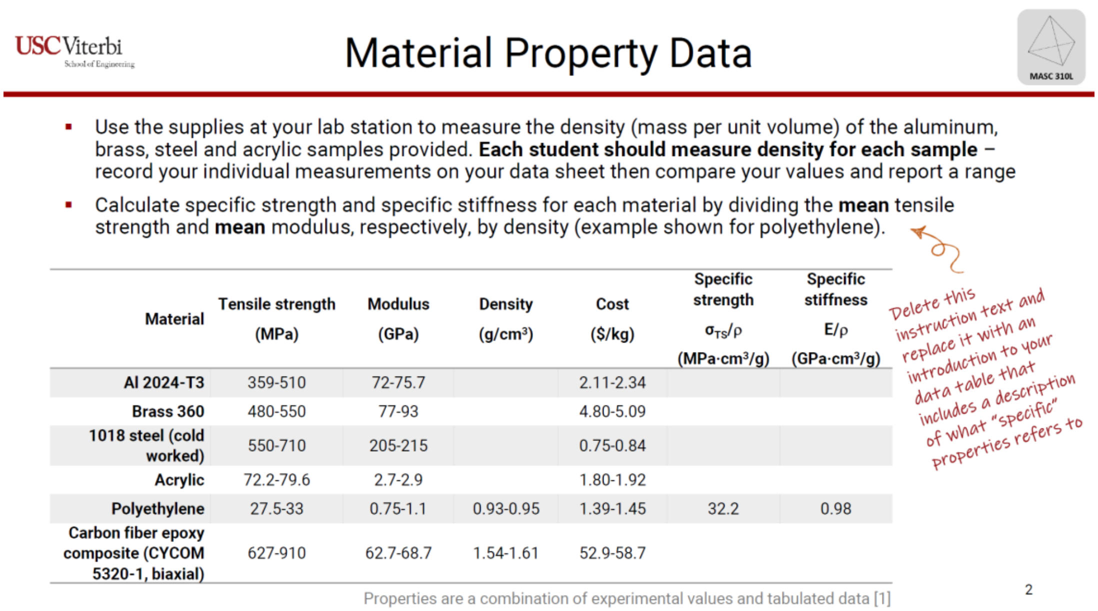

Figure 4. First content slide of the material comparisons Slidedoc template, containing instructions to students and a partially completed data table

The next several slides in the template address various aspects of material properties and end-use applications. Students are first asked to compare typical tensile strength values for metals to those of polymers and to use their knowledge of atomic structure, bonding, and deformation mechanisms to explain the differences observed between the two material families. They then compare the specific tensile strengths of metals and polymers and identify how the relative property values change when density is incorporated into the analysis. The distinction between absolute (raw) property values and specific property values is further developed on a slide titled

“Matching Properties to Applications” on which students are instructed to conduct brief background research to identify the primary end-use market for the material with the highest modulus (steel) and to contrast it with the primary market for the material exhibiting the highest specific stiffness.

The next page of the Slidedoc prompts students to address another key factor in the real-world application of materials: durability. Durability rankings are provided for the six materials examined in the activity and students are asked to use observations of passive corrosion to compare accepted rankings to the actual condition of each material after both short-term and prolonged exposure to a seawater environment.

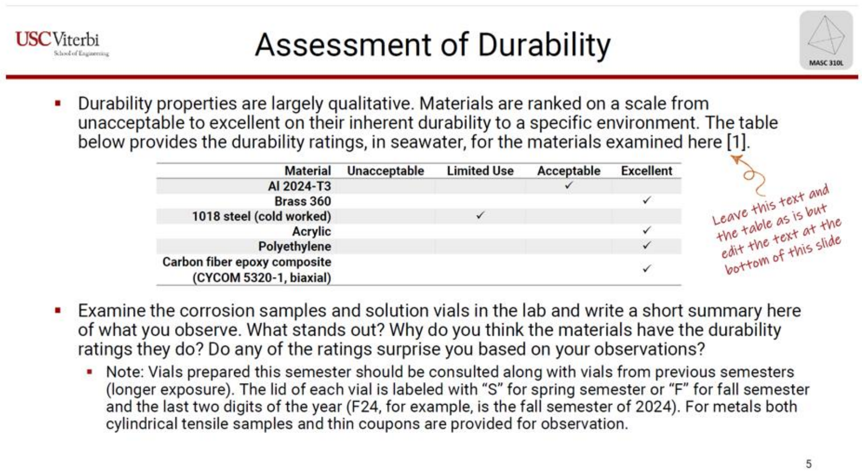

Figure 5. Left: students examine material samples partially submerged in simulated seawater. Right: Slidedoc template page addressing material durability.

Considering absolute and specific material properties, cost, and durability, students are next tasked with selecting one of the materials evaluated in the activity for use in the frame of a beach cruiser bicycle. Students must provide clear justification to support their material selection. On a subsequent slide, students are asked to select a material for a high-performance racing bicycle and to again explain and justify their choice. Although both prompts involve the same component (a bicycle frame) the underlying performance requirements and design priorities differ substantially between a low-cost beach cruiser intended for general transportation and a high-performance racing bicycle optimized for weight and efficiency. This conveys to students, through a simple and relatable example, that material selection decisions are context dependent. This framing helps students move beyond viewing material properties in isolation and toward understanding materials as design-enabling elements within broader engineering systems.

The final slide, titled “Additional Considerations,” prompts students to identify a material property or attribute not previously examined in the Slidedoc that would be important to consider before finalizing material selection for a bicycle frame. This open-ended question requires students to name and define their selected property and to explain its relevance to the requirements of the application. In this way, students revisit content addressed throughout the semester and extend the exercise to acknowledge the complexities of the selection process.

Concluding Remarks

The material comparisons activity described here provides a low-cost, adaptable laboratory experience that supports both technical and professional learning outcomes. Its structure and deliverables can be readily modified to suit a range of instructional contexts. By integrating hands-on measurement, data-driven analysis, and application-focused decision making, the activity bridges the gap between material properties and engineering design considerations. Implemented using supplies already available in most instructional laboratories, the activity intentionally incorporates several aspects of the laboratory experience valued by both students and future employers [4]:

- **Teamwork:** Students are responsible for making independent measurements and observations, but must work collaboratively to compile results and develop responses to guided questions.
- **Hands-on experimentation:** Although a comparison exercise could be completed without a physical laboratory component, generating and analyzing data and physically handling material samples creates a more engaging and memorable learning experience.
- **Real-world relevance:** Through targeted materials selection prompts, students connect the materials they have tested throughout the semester to engineered products, providing context for their learning that extends beyond the classroom.
- **Industry-oriented technical communication:** Rather than simply completing measurements or calculations, students are guided through the creation of a Slidedoc. This exposes them to an increasingly common form of technical communication and produces an archival document they can revisit as a reference.

Student responses to the activity have been favorable. They are visibly engaged during the laboratory session and consistently produce thoughtful, high-quality Slidedocs that demonstrate both technical understanding and application-driven reasoning. The activity provides a natural and effective conclusion to the course, reinforcing key concepts while highlighting their relevance to real-world engineering practice.

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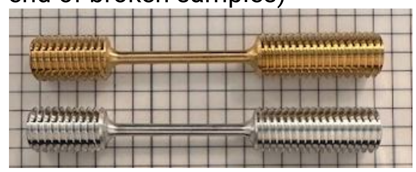
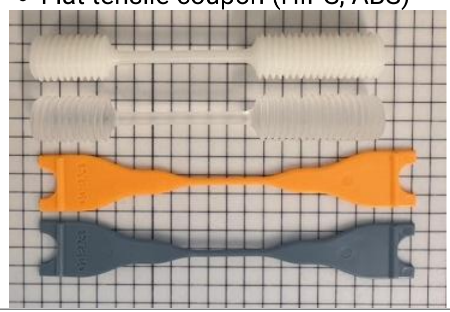
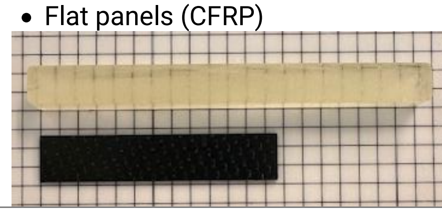
Appendix: Materials and sample format by experiment. Photographs are presented on a 5mm×5mm grid for scale. Tensile samples of each material are used for passive corrosion.

Week	Material(s) tested	Experimental methods	Sample form and supplier
3	Brass 360, 2024-T3 aluminum	Tensile and shear – load frame with tensile grips and shear testing accessory	Threaded cylindrical tensile sample (Vickers indentation performed on flat end of broken samples) 
4		Vicker's microindentation	
5	Polyethylene, Polymethyl methacrylate, Acrylonitrile butadiene styrene, High impact polystyrene	Tensile – load frame with coupon testing fixture	• Threaded cylindrical tensile sample (PE, PMMA) • Flat tensile coupon (HIPS, ABS) 
7	Brass 385	Cold working via rolling mill and Vicker's microindentation	Bar stock 
8	1018 steel, brass 385	Annealing (furnace), Vicker's microindentation, tensile testing	• Threaded cylindrical tensile sample (1018 steel, annealed and cold worked) • Bar stock (Brass 385)  
9	1018 steel	Heat treatment and Vicker's microindentation	• Bar stock 
12	Carbon fiber epoxy prepreg, glass fiber and two-part epoxy	Wet layup and casting of GFRP beams, prepreg layup and vacuum bagging of CFRP panels	• Beams (GFRP) • Flat panels (CFRP) 
13		Three-point-bending – load frame with bend test fixture	