AC 2007-1906: MATERIALS SELECTION EXERCISES BASED ON CURRENT EVENTS

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Materials Selection Exercises based on Current Events

Abstract

Issues relating to a wide range of consumer and industrial products appear in newspaper articles and on a variety of television shows, every day**.** These exercises were developed to give engineering students a societal and global perspective on technical problems important to the general public. Beginning with the concerns brought to light in a newspaper article, students employed their knowledge of material selection methodology and engineering principles to investigate the implication of the choice of materials. The CES EduPack 2005 Materials Selection software is utilized as the primary tool to provide the technical support for their analysis, conclusions, and comments. The general format of the exercises presented here includes the task outline, materials selection techniques, specifications for oral and written assignments, and the in-class activities and discussions. The exercises were implemented based on two newspaper headlines, "Marines Say Body Armor Too Heavy" and **"**Mission: Design Better (Space) Gloves". Samples of student work highlighted the different skill levels of achieved by students applying the techniques of material selection, as well as, the unique perspective of individual students to solving and/or commenting on these open end problems. With their ability to share results through presentations, students were teaching students. The peer evaluations developed a positive classroom environment promoting creativity and improvement in the technical content of subsequent projects. Students began to see the connections between the public concerns and opinions, and their role as engineers in the design, development or manufacture of a product. The possibilities for media examples are endless and provide students and faculty with a wide range of ideas to promote interest, motivation and a learning opportunity for today's engineering student.

Introduction

Do we take the material of a product for granted, or do we look at a product and remember what it used to be made of? Do we ever stop to think about what our daily lives would be like if scientists hadn't explored the properties of silicon or polymers? Do we realize materials and the importance of materials selection touches our lives everyday through the mass media? Most technically oriented people, including engineering students and faculty, enjoy watching

Discovery Channel ™ and History Channel ™ television shows like Modern Marvels, Engineering Disasters, and Extreme Engineering or reading trade magazines associated with their industry or hobbies, or hitting the favorite technical sites on the web. Often transportation accidents, infrastructure failures, accidental injuries or deaths due to use (or misuse) of products, consumer recalls are covered by in the national and local news on television and in print. Engineers usually take notice, and with their technical training, tend to 'read between the lines' of article or report written for the general public.

With a 'keen eye' and a passion for materials science problems, an instructor can identify public interest stories from the mass media and develop instructional exercises in the area of materials selection. Current events are on the student's 'radar' and immediately generate interest, without obviously favoring someone with a specific academic or personal background. The event or topic selected provides the catalyst for implementing the methodology pertinent to materials selection yet allows the students to take creative approaches to developing their 'solutions'. The proposed exercises will attempt to add technical depth and perspective to the student's reaction to the event, versus just opinions based on personal background and life experiences.

Development and Implementation

In the context of a materials selection course, current events were used generate student interest and provide the 'good examples' for developing exercises and assignments. Two exercises will be presented here, the first having an open ended approach with minimal guidance in the problem statement and assignment deliverables, and the second being a more focused approach with significant amount of guidance in the problem statement and specific requirements for assessment.

At the instructor's home institution, the **catalog description** for Special Topics- Materials Selection and Engineering Design and Manufacturing is as follows.

> "The course will develop a systematic approach for the development of a new idea or product and facilitate the continuous improvement processes for products currently on the market. The approach is based on evaluating open-ended design problems with respect to the interrelationship between material, shape, function and processes used to produce a variety of products. In the course, the design process and engineering materials and their properties will be explored using the

materials selection charts and the CES Materials Selection software. Case studies and team projects will focus on materials selection and multiple constraints, the factors involved in materials processing and design, and the use of data sources. The students completing this course will have useful solutions to standard problems in industry and a working knowledge of the materials selection software. The methods of assessing students include homework, quizzes, a midterm exam, design project report(s) and a final exam." *3 cr.*

The students were required to have the following **text, software** and ancillary materials.

Text – Ashby, Michael F., Materials Selection in Mechanical Design, Third Edition, Elsevier Butterworth Heinemann © 2005

Software - CES EDUPack 2005; Virtual Classroom account for the course; memory stick

The **participants** in this course were part-time Masters' Degree students, who are young, working professionals looking to improve their engineering skills to better compete in the workplace. Students have backgrounds in mechanical or industrial engineering and work as engineers in the areas of production support, test and project management. Only 1-3 years past graduation with their Bachelors' degree and significant entry level experience at their companies, these students are eager learners. For most students, a Master's Degree will be their highest level of technical education attained. It is noted here that upper level undergraduates, who have completed courses in design, materials, manufacturing processes and mechanics of materials, fulfill the prerequisites to meet the outcomes related to the example exercises.

The general set of outcomes for the course incorporates the philosophy and methodology of materials selection, the proficiency with the CES EDUPack software, and ability to apply the design process to solve real world problems.

The **learning outcomes** develop knowledge and skills to select materials and processes, and determine a configuration to meet the need of an engineering problem and its design constraints defined by the consumer and/or industry. Student will explore the following ideas in engineering design:

1) sensible translation of the design requirements into material constraints and design objectives,
2) 'good judgment' in the positioning of selection lines on the materials selection charts (i.e. use of CES EDUPack software) and,
3) reflect on the implications of the material(s) selected for the 'product'.

The philosophy and methodology adopted throughout the Materials Selection and Engineering Design and Manufacturing course, is that presented in the text by Michael Ashby, Materials Selection in Mechanical Design, Third Edition. The exercises propose using the "Ashby's philosophy" outlined in Figure 1.

Strategy for Materials Selection [1]

All materials →

Translate design requirements →

Screen using constraints →

Rank using objective→

Seek supporting information →

FINAL MATERIAL CHOICE

Figure 1. 'Ashby's philosophy' for materials selection (Phrase coined by the students)

From the point of view of the instructor, it is critical to emphasize the selection process itself and encourage students to buy into the "Ashby philosophy" and be open-minded with their results. Proper technical justification must be encouraged and the degree of subjectivity in the solutions for the final choice of materials must be discussed.

The **CES EduPack 2005 Materials Selection software** is utilized as the primary tool to provide the technical support for the analysis, conclusions, and comments. Often, each student would be assigned a different textbook example to work out in detail, and then present it to the class for discussion. Students taught students how best to use the software. The CES EDUPack 2005 materials selection software used to explore several topics presented in Ashby text and highlighted as follows: 1) general requirements of the materials universe; 2) use of material selection charts, 3) translation of design problems into engineering terms (or material properties tabulated in the software), 4) derivation and use the material indices, and 5) exploration of the process universe. Advanced concepts including multiple constraints and objectives, and selection of material and shape were studied with the CES software. The examples from the textbook were subsequently incorporated, to some degree, in the design exercises.

The focus of the exercises and corresponding assignments is to have students apply materials selection methodology, i.e., "The Ashby Philosophy", in the design process while solving real world problems. In Figure 2, the Design Table provides the framework for student responses to design problems posed in mainstream news articles.

The Design Table: Approach to Materials Selection

Function

Constraints → translation to engineering term

Objectives

Free variables

Figure 2. The Design Table[1]

In summary, students began the exercises on common ground, with the design table, a knowledge base in materials selection, and skills using the CES EduPack software. As will be shown, it provides a degree of uniformity in student responses, yet leaves room for professional judgment and creativity in solving problems.

The Exercises: Two Scenarios

Beginning with the concerns brought to light in the newspaper articles, students employ their knowledge of material selection methodology and engineering principles to investigate the implication of the choice of materials. In the first exercise, the outcomes are addressed with an open ended assignment with minimal guidance and defined requirements. The second exercise has a more focused approach with significant amount of guidance in the problem statement and assignment deliverables. It includes more specifications, which force certain result, and provides an assessment tool that measures the ability of all students to implement materials selections tools and methodology. Depending on the outcomes and the necessary assessment, each exercise has potential benefits for student learning.

Exercise #1 : Body Armor for the Military

Newpaper article quote: "Extra body armor – the lack of which caused a political storm in the United States- has flooded into Iraq, but many Marines promptly stuck it in lockers or under bunks. They are too heavy and cumbersome, many say. …….”We have to climb over walls and go through windows,” said Sgt., “I understand the more armor, the safer you are. But it makes you slower.”” The Hartford Courant, Monday, March 27, 2006

Question Posed: How could we use our knowledge of materials selection to design better armor?

Assignment: Read the newspaper article. Utilize your knowledge of materials selection to prepare 1) oral presentation, 7-10 minute in length on Power Point, and 2) write a technical memo summarizing your approach. The due date is one week from the date assigned and expect to answer questions and participate in an active class discussion.

Table 1. Body Armor : Summary of Design Tables submitted by students

EXERCISE: **Body Armor**	**Student 1**	**Student 2**	**Student 3**	**Student 4**	**Student 5**	**Student 6**
Function	Deform bullet; Absorb energy; Slow down bullet	N/A	Protect human body from bullets and shrapnel	Body armor	Military body armor	Body armor
Constraints	Geometry defined; Energy absorption require-ment defined	N/A	High tensile strength & high fracture toughness; Can not degrade over time; Fixed shape	Must not fail by yielding; Must be tough; Plate thickness	Material must be flexible; Must not fail	Must be light weight, 5 lbs.; Must absorb energy; Must stop and/or deflect bullet/ shrapnel
Objective	N/A	N/A	Light-weight, Flexible; Min. cost	Minimize mass	Minimize mass; Minimize cost	Minimize mass
Free variables	Material	N/A	Thickness; Material; Process	Choice of material	Choice of material	Choice of material

Student responses in Table 1 show their use of the design table as the primary way to begin the material selection problem. The determination of the function tends to focus on the product, but student should be reminded broader descriptions, e.g. in student 3 response, are desirable and may expand selection over a wide range of materials. The objective and free variables are well understood and recorded by students. The constraints prove to be more challenging, noting care must be taken to translate common language to measurable or tabulated engineering properties. The oral presentations often focused on the constraints in the design solution and subsequently, provided for lively class discussions. This in-class activity, with input form the instructor and peers, provided a valuable learning experience for all students. For example, Student 3 included degradation and Student 6 worked on translation of "must stop and/or deflect bullet/shrapnel". This dialogue helps explore design possibilities versus 'right and wrong' answers, the designer's personal biases, and debate with technical substance. The information provided in the design table leads directly into the strategies and tools used to make the materials selection as shown in Table 2.

Table 2. Body Armor: Summary of Materials Selection Tools Used by Students

Exercise: Body Armor Materials Selection strategies used by students	**Student 1**	**Student 2**	**Student 3**	**Student 4**	**Student 5**	**Student 6**
Prior research	✓	✓	✓	--	✓	--
Design table	✓		✓	✓	✓	✓
CES tool- Material record / property	✓	✓	✓	--	--	--
CES tool-Model *(Sketch: tie, beam, shaft, column, etc.)*	--	--	--	--	--	--
CES tool: Selection chart *(simple)*		✓	✓	✓	✓	✓
CES tool: Selection chart *(complex axis parameter/ material index)*	✓	--	✓	--	--	--
CES tool: Limit stage	--	--	✓	✓	✓	✓
CES tool : Advanced techniques	✓	--	--	--	--	--

Sample of simple selection chart & limit stage

The limited guidance led most students to start with their usual engineering problem solving techniques, that is, basic research into body armor, then the materials selection tasks, and confirmation of the material choices with their original research. The CES materials records, which provided a technical summary of a material, proved useful to the students and increased their knowledge of different materials**.** Students did find good results with the implementation of the materials selection strategies, even just focusing on simple constraints and upper/lower limit criteria. Two samples of student response using the CES materials selection charts and simple limit lines are shown in Figure 3.

Student response:
Must not fracture
Ref. W Huff

Student response:
Material must absorb large amount of energy without fracture and be light weight. Energy is maximized by choosing materials with large values of Toughness: $J_c = K^2_{1C} / E$
Ref. W Huff

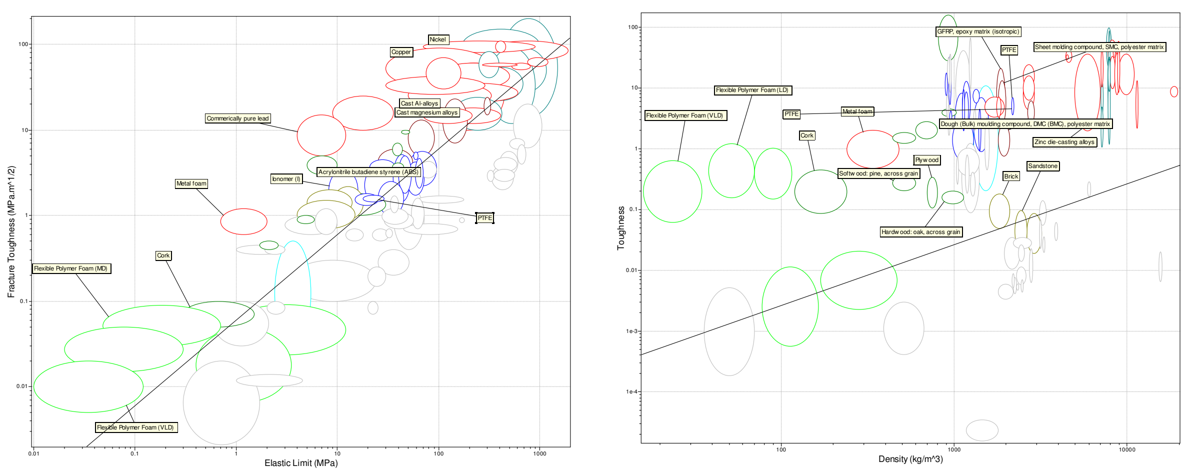


Figure 3. Example of student response to Exercise #1- Body Armor for the Military

The drawback seen here is the lack of models and advanced methods used in problem solving, however, the class discussion allowed students to see how advanced strategies provided a solid technical and well justified response. In other words, one student did not have all the right answers, but compilation of work and ideas yielded valuable technical information and strategies students would implement in future work.

Exercise # 2: MISSION: DESIGN BETTER GLOVES

Newpaper article quote: **Hartford Courant article on April 24, 2006**

> "The space program wants a hand in making better gloves.
> NASA is daring the nation's inventors to improve on the gloves now worn by space-walking astronauts.
> And to encourage them, the space agency and its partners on Monday launched the 2006-2007 Astronaut Glove Challenge during a meeting at the New England Air museum."
>
> *(A copy of the article was distributed in class on Tuesday, 4/25/06.)*

Website: http://www.astronaut-glove.us

Our mission is to design a better space glove or at least, investigate the selection of materials for this application. Our challenge is to use our knowledge of the on material selection and complement it with use of the CES EDUPACK2005 material selection software.

General requirements:
Presentation: Share your design ideas and methodology with the class in an 8-10 minute PowerPoint presentation. See suggested specification below.
Technical Memo: Your memo should explain your design and material selection philosophy and methodology, that is, provide technical information to justify your choices. You may reference your PowerPoint slides for supporting figures, tables and materials selection charts, etc..

Suggested topics for including in your work:

- Discuss "**The Design Process**": Market Need (design requirements) → Concept → Embodiment→ Detail → Product Specification
- Develop a **strategy for material selection**: All materials → Translate design requirements → Screen using constraints → Rank using objective→ Seek supporting information → FINAL MATERIAL CHOICE
- Develop the **design table** for this application. Describe: Function, Constraints, Objective, and Free Variables
- Model and sketch a **schematic diagram** of your ideas of a space glove (to support your design table and derive your Materials Index)
- Establish an appropriate **material index** (M) for selecting materials for the space gloves, that is, the simplified model you determined to be best for your work.
- Use this information and the CES software to find candidate materials for your space gloves. Include all the constraints presented in this problem to search for candidate materials. **Present your materials selection charts (including limit stages, etc.) and a table of your candidate materials.**
- As part of the evaluation of material choices, comment on the choices (yielded by the CES software) and add any practical insight into minimizing and/or optimizing the space gloves. Look at interaction between function, material, shape and process. You might comment on a manufacturing process for the candidate materials, i.e., what process and general information from the CES Process universe record. Or other considerations you find important, e.g. shape

factor (material dependent), environment, etc. (*Note: This is open ended and will most likely be dependent on your simplified model and assumptions.)*

☝ Reflect on your materials selection process and candidate materials then, write a summary statement on the **strategy for materials selection**. Outline your response based on the four main steps – *translation, screening, ranking and supporting information*- in your answer.

☝ *Note:* The personal background and insights of the students in our class have lead to some great presentations, excellent learning and interesting discussions. Below is a *brief* check list for your reference. Continue the good work and showcase your depth of knowledge of the CES software and design philosophies in this work.

Suggested 'checklist' for our mission:

1) Problem statement with sketch
2) Design requirements table
3) Develop material index (M) and limits
4) Show materials selection charts / tables
5) Justify / comment on various aspects of candidate materials
6) Reflect on overall strategy for materials selection!

Table 3. Space Glove: Summary of Design Tables submitted by students

EXERCISE: **Space Gloves**	**Student 1**	**Student 2**	**Student 3**	**Student 4**	**Student 5**	**Student 6**
Function	Flexible, strong; Corrosion resistant; Thermal insulator	Glove	Gloves for outer space	Space Glove	Astronaut Space Gloves	Space glove
Constraints	Must be capable of withstanding outer space environment & internal pressures	Must not fail by yielding; Diameter & length specified; Pressure specified	Cannot fail under pressure → high elastic limit; Length & width fixed; Water & UV resistant; Good insulator	No failure, $\sigma < \sigma_f$ Support pressure difference, Δp Light weight; Radius specified	Must not fail by fracture toughness;	Very flexible (minimum stiffness); Strong and durable; Length and shape defined
Objective	Come up with a design that meets all of the	Minimize mass	Flexible; lightweight	Min. elastic flexure; must not fail by yielding or	Minimize mass; Maximize flexibility	Minimize mass

	constraints			by fracture; Min. mass		
Free variables	Material; Design; Manufact-uring Methods	Choice of material	Thickness; Material; process	Choice of material; Wall thickness	Choice of material	Thickness of material; Choice of material

Student responses in Table 3 show their use of the design table as the primary way to begin the material selection problem. As in exercise #1, the determination of the function tends to focus on the product, but student should be reminded broader descriptions, e.g. in student 1 response. The presentation of the design problem itself, i.e., Space Gloves, may strongly influence student responses. The objective and free variables is well understood and recorded by all students. The constraints are more detailed and described in terms of measurable or tabulated engineering properties that can be utilized in the CES software. Again, the discussions in the oral presentations often focused on the constraints and benefited from the input of peers and the instructor. In both exercises, the in-class activity provided a valuable learning experience for all students.

Table 4. Space Gloves – Summary of Materials Selection Tools used by Students

Exercise: Space Gloves Materials Selection strategies used by students	**Student 1**	**Student 2**	**Student 3**	**Student 4**	**Student 5**	**Student 6**
Prior research	✓	✓	✓	✓	✓	✓
Design table	✓	✓	✓	✓	✓	✓
CES tool- Material record / property	✓	✓	✓	✓	--	✓
CES tool-Model (*Sketch: tie, beam, shaft, column, etc.)*	✓	✓	✓	✓	--	✓
CES tool: Selection chart *(simple)*	✓	✓	✓	✓	✓	✓
CES tool: Selection chart *(complex axis parameter/ material index)*	✓	--	✓	✓	--	✓
CES tool: Limit stage	✓	✓	✓	✓	✓	✓
CES tool : Advanced techniques	✓	--	--	--	--	--

The significant guidance provided in Exercise #2 forced students to start with materials selection technique, in order to fully take advantage of the "Materials Universe" in the CES software. As seen in Table 4, five of the six students implemented a model to develop appropriate Material Indices for use in the CES software. A sample of the modeling technique used by one student is shown in Figure 4. The material selection charts, shown in Figure 5, contain the Material Index developed from these models. This information, combined with limit stages, yielded a technically sound response to the design problem. Creativity and originality in solving the design problem was not squelched in all the assignment guidelines, as shown in another student response in Figure 6. The premise of the design was two layers in the gloves, each addressing key engineering properties used in conjunction with the CES software. Figure 7 shows the use of Limit stages and the possible materials for each layer. It is noteworthy to mention that all students were required to analyze candidate materials discovered with the CES software and provide additional supporting information to narrow down the list to practical and realistic choices.

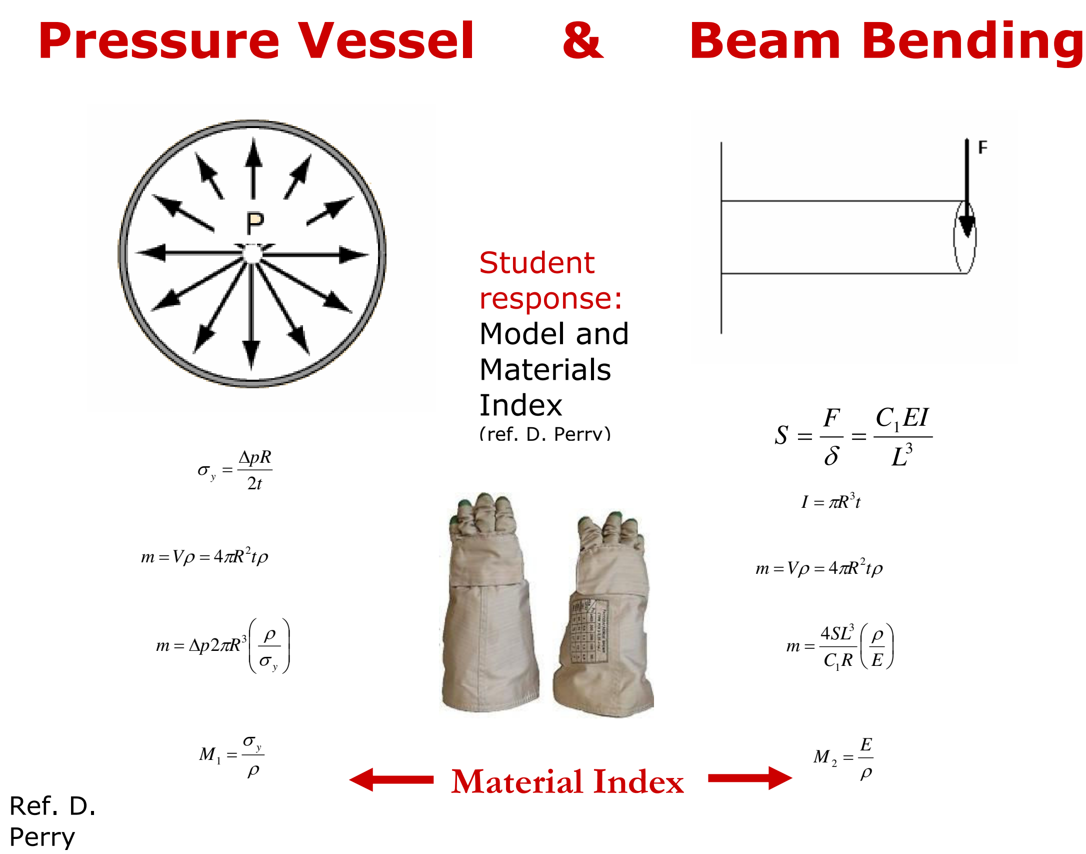
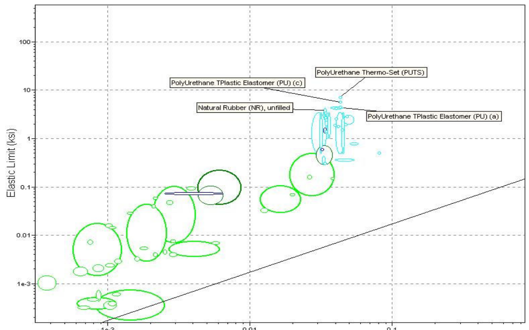


Figure 4. Example of student response to Exercise #2 – Mission: Design Better Gloves

Student Response:
Elastic Limit vs. Material Density



Ref. D. Perry

Student Response:
Young's Modulus vs. Material Density

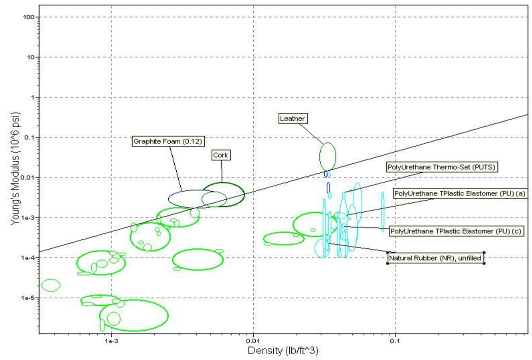


Figure 5. Example use of Materials Selection Charts in Exercise #2 (refer to Fig. 4)

Student response (alternative approach):
Proposed Glove Construction
Ref. C. Muller

The glove is required to be made out of two layers and two different materials. Each layer will be designed to satisfy a different requirement.

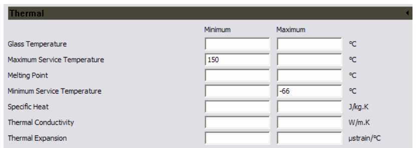
Layer 1 – Inside Layer

Layer 2 – Outside Layer

Figure 6. Example of student response to Exercise #2 – Mission: Design Better Gloves

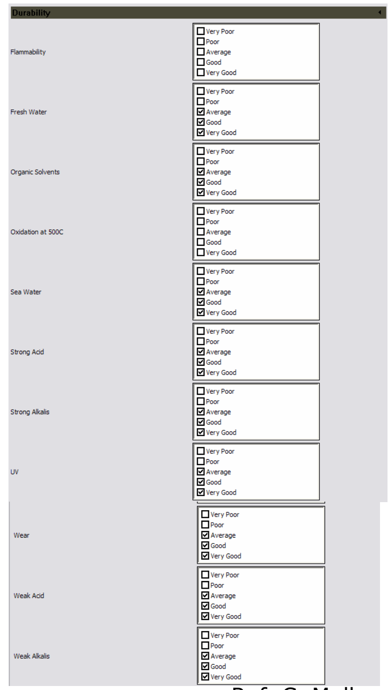
Student response: Space gloves

Layer 1 –Stage 3 A limit stage was used to eliminate materials that are not suitable for the space glove



After the four stages were implemented the following materials were left:

ETFE, PCTFE, PTFE,
Eccosil 4122 (SIL) – Terpolymer (EPDM),
Ethylene Propylene Terpolymer (EPDM),
Silastic 590 (SIL) – Silicone Elastomer

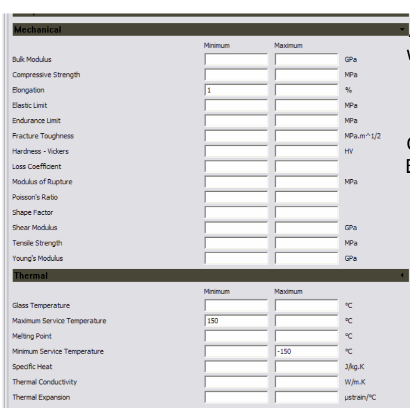


Ref. C. Muller

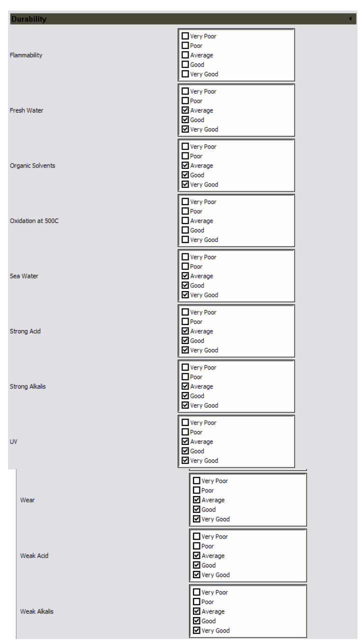
Figure 7. Example of student response to Exercise #2 – Using limit stages for Layer 1

Student response: Space gloves

Layer 2 - Stage 3 A limit stage was used to eliminate materials that are not suitable for the space glove.



After the three stages were implemented the following materials were left:
Aluminum/Boron Composite; Beryllium; Beryllium, Grade I-25-, HIP'ed; Ti-35% SiC (f), Unidirectional, Longitudinal; Ti-38% B4C (f), Longitudinal



Ref. C. Muller

Figure 8. Example of student response to Exercise #2 – Using limit stages for Layer 2

The positive side of Exercise #2 is the use of models and advanced methods used in problem solving. The guidance, outlined in the assignment, encompassed all the materials selection skills and methodology presented throughout the course. Additionally, the creativity and originality of design ideas and techniques employed to arrive at a solution still provided for lively class discussion and technical debate.

Comparison of Exercises

- ☐ Exercises and assignments with little guidance allows for very different student presentations and interesting use of materials selection strategies (or lack there of), however, assessment is difficult.

- ☐ Exercises and assignments with a lot of guidance limits student responses but allows for equal and standard assessment.

Instructor comments and observations

The instructor has made qualitative observation based on the results of the exercises and about student learning throughout the materials selection course. The comments are as follows.

- Students must be encouraged to adopt the "Ashby philosophy" and methodology for materials selection and resist choosing materials based on personal experience only.
- Hands-on activities in class and easy access to software outside of class facilitate learning and promote students helping students.
- Assignments should be open-ended, real-world problems to allow students to implement the 'necessary' strategies and realize there is more that one right answer or that the solution is not just a 'boxed number'.
- Technical justification in your responses is most important, so the more material selection strategies used, the better.
- Oral presentations in class proved to be very instructive and again, allowed students to teach students. It was instructive for student to see the different approaches taken to the same problem. Interestingly, it takes a while to develop a positive atmosphere for class discussion versus one of grading and critical evaluation.
-

- During the course, students ‘mature’ with their engineering vocabulary, e.g. strong becomes high tensile strength, flexible becomes low Young’s Modulus, and replacing common language with engineering properties.
- Future exercises can also have a historical component, since the materials resulting from the selection process often show the product development.
- Exercises based by current events can be adapted to any group of students at all levels of their engineering education with the proper level of instruction, and clearly defined expectations, including the learning outcomes and assessment method and rubric.

Student comments

Based on conversations with the students, the instructor has noted the following comments from students and they are as follows.

- “Most class participation I have ever had in an engineering course…”
- “This software could be useful at work…..” (provided my company purchased it!)
- “Couldn’t fool the software; I was able to match the materials specified for the products I work with……”
- “Using software was really helpful and I was often surprised what materials came up…….”
- “Helpful at work, even if material is already specified, I have a better idea why, and what some alternative might be in the future (or in its history)…”
- ”Just interesting to fool around with the software at home…learned a lot that way…..”

In summary, students agreed that this was a useful course for their professional development at their work places and engineering careers, and that they would recommend it to others.

Summary

Exercises prompted by current events can be adapted to any group of students at all levels of their engineering education with the proper level of instruction, and clearly defined expectations, including the learning outcomes and assessment. The knowledge of the vocabulary or terminology, basic process parameters and unique characteristics associated with each process, is required and ability to work with the CES EDUPack Materials Selection software is essential.

As demonstrated by these two exercises, assignments must be thoughtfully developed to maintain technical rigor in material selection methodology, yet promote creativity and originality in engineering problem solving.

Future Work

The flexibility of these exercises can be adapted to any group of students and may also focus on the group's personal or professional interests. So, current events in mass media, newspapers and magazines have the potential to lead to the development of materials selection exercises. Other possible applications may be in a manufacturing processes course, product design application, and a capstone design projects. Utilization of the CES EDUPack software can be implemented in a variety of ways, from information attained on the material records to setting up limit stages to narrowing the choices of materials. In future exercises, formal work on the connections between public concerns and opinions, as related to the role of the engineer, will be included. Attention to outcomes and assessment will allow the instructor to provide a learning experience that will promote the student's development in the engineering profession.

References:

Ashby, Michael F., Materials Selection in Mechanical Design, Third Edition, Elsevier Butterworth Heinemann © 2005