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Assessments of Material Selection Activities in Undergraduate Reverse Engineering Projects

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ASSESSMENT OF MATERIAL SCIENCE ACTIVITIES IN UNDERGRADUATE REVERSE ENGINEERING PROJECTS

ABSTRACT

This work involved the assessment of the material science activities in reverse engineering projects associated with the sophomore engineering course "Introduction to Mechanical Engineering Practice." About 180 students in the class were broken into groups of four students and each group chose a specific product to be dissected and analyzed in detail. Two lectures were devoted to material selection in mechanical design where the Ashby charts were introduced. One of the areas that the students looked at was to determine the material and manufacturing process used for each component within their chosen product. The products ranged from electric drills, radio controlled cars, door knobs, Nerf guns, etc. The students were expected to explain in detail why a particular material was chosen for a subcomponent of their chosen part and also why a particular manufacturing process was used for the production of that part. They were also required to suggest alternative materials and rank the various materials that can be used for their products. This would then require them to investigate the mechanical properties of the component materials and relate them to the product performance, the life cycle, manufacturing process and the environmental impact. This work summarizes the overall experience of the students on the material and process selection for a wide range of commercial products and possible ways to improve the teaching of this course.

INTRODUCTION

This work is an attempt to create awareness in early engineering students as to how materials and manufacturing processes are chosen for different consumer products. To this end, the project component of a sophomore course dealing with reverse engineering has been employed. This course is entitled "Introduction to Mechanical Engineering Practice," and is a required course for mechanical engineering majors. The course comprised of three hour-long lectures every week along with a group project in reverse engineering. The lecture classes were devoted to the basic elements of mechanical engineering practice which came from a text entitled "An Introduction to Mechanical Engineering."[1] This text introduced the students to the vocabulary, skills, and applications associated with the mechanical engineering profession. Chapter 1 of the text introduces the profession of mechanical engineering, and the next seven chapters talk about the various disciplines within mechanical engineering with intent to develop useful design, analysis and technical problem solving skills in students. In addition to the topics presented in the text, Engineering Ethics and Material Selection were introduced as separate lectures.

The reverse engineering project involved dissecting a product that the students chose and then put it back together. 180 students in the class were broken into groups of four students and each group chose a specific product to be dissected and analyzed in detail. In this process the students got a broader perspective on engineering decisions. For the product dissected the responsible group investigated the design, answering questions about functionality, aesthetics, manufacturing and other engineering decisions. In doing so, the students explored the global, societal, environmental, and economic factors that shaped the final design of the product. This process of reconstructing the lifecycle of the product – the customer requirements, the design specifications (including material selection) and the manufacturing processes used to produce it – to understand the decisions that led to its development is known as product archaeology. [2] In this work only the material selection process has been examined in detail. Although the students at this level have very little background on materials, it is believed that the students gain a fresh perspective as to how and why a material is selected for a specific component of the product as they are introduced to a rational way of selecting materials.

PROJECT DESCRIPTION

The projects that the students worked on were broken into four stages or gates. For each gate, the groups completed a set of product archaeology and project management tasks. Before their gates began, each group submitted a project proposal identifying what products they as a group would investigate. The individual gates are identified below and were pursued for all projects.

Gate 1 was the preparation and initial assessment phase, where the students researched the background of the product and performed a preliminary evaluation. At this Gate, the students hypothesized the inner working of the product before it was dissected.

Gate 2 involved the process of dissection (or excavation using the language of product archaeology). In this Gate, the students dissected the product to collect additional detailed information about how the products were manufactured, how do the various components within a particular product interacted, and so on.

Gate 3 was the evaluation phase, where the students analyzed the information already obtained in Gate 2. Here the students performed basic analyses and tests to establish the design of the components within the product, and also the overall product design.

Gate 4 was the explanation phase, where the students synthesize the information obtained to make large conclusions about the design decisions.

For each Gate, all the groups completed and submitted individual Gate reports. Upon the completion of all four Gates, the students documented their findings in the final report that they prepared for critical review by the instructor with the help of two teaching assistants. Gates were submitted throughout the semester, evaluated, and returned to the students. The reports contained the required discussion, figures, tables, videos or any other supporting information. The individual Gate reports together with the final report, constituted the project grade, which accounted for 30% of the course grade. The rest of the course grade came from the mid-semester examinations and homework based on lecture topics. Because of the large class, individual oral project presentations were not scheduled in the interest of time. A project of this magnitude was a big challenge for students. The students got access to all the facilities and resources of the university. There was a dissection laboratory which was equipped with power tools, hand tools, and measurement devices. In addition, the facilities of the Engineering Machine Shop were accessible for difficult disassembly and assembly tasks.

MATERIALS SCIENCE PERSPECTIVES

The work reported here addressed the material selection aspect associated with each individual product that was reverse engineered. This provided the material science perspectives of the product archaeology. Typically this originated in Gate 3 and evaluated in detail in Gate 4. The background of the early engineering students in materials science was grossly inadequate. Therefore they were provided some basics on materials in the lecture classes. A total of five lectures were devoted for that purpose. The variety of materials, namely metals, ceramics, polymers, and composites was discussed. The key concepts introduced were stress, strain, elastic modulus, yield strength, etc. In addition they were exposed to the different failure modes, namely those of tension, bending, and torsion, along with buckling. The students were presented with normal and shear stresses and warned that they are separate entities and could not be added as such. The stresses due to tension and bending were to be evaluated against the material yield strength, while shears stresses were to be evaluated against one half of the yield strength. The equations for tensile/compressive stresses were presented in terms of the applied load divided by area, the equation for bending stress in terms of the applied moment and cross sectional properties, and the one for torsional stress in terms of applied torque and sectional properties. Some practice problems on these topics were done in the class and supplemented by homework problems. The individual groups were assisted by identifying loads that are applied on the components of their product and how to calculate the stresses due to applied loadings and assure structural adequacy through comparison with the corresponding allowable stresses.

Separate lectures were presented on materials selection. The students were made aware of the fact that a designer had to choose the material best suited for the specific situation from a vast menu of materials. The material selection decision could be effectively performed using Ashby's book [3] and elements from the Cambridge Engineering Selector [4]. The software CES EduPack[4] was not used, but was planned to be used the next offering of the course. To establish the rational way of material selection, the concept of the material indices as discussed in Ashby's text [3] was briefly mentioned. These indices established the optimum choice of material, without

solving the complete design problem. Reference [3] discusses a wide range of situations involving a variety of loadings. For the purpose of illustration only two cases were considered along with the associated material indices. It was felt that most of the loadings associated with the products analyzed by the students could be viewed in terms the following two loading scenarios:
:

(a) Design of a light stiff beam in bending
(b) Design of a light strong beam in bending

It was left up to the students to use the loading appropriate to their product. They were expected to find the material properties of the various components of their products from literature. The specific properties were the density, ρ, the elastic modulus E, and the yield strength, σ_y. The material indices associated for the scenarios (a) and (b) denoted by M_1 and M_2 respectively and are given by [3]:

$$M_1 = \frac{E^{1/2}}{\rho} \qquad (1)$$

:
And,

$$M_2 = \frac{{\sigma_y}^{2/3}}{\rho} \qquad (2)$$

To illustrate the procedure, examples using steel, aluminum, and plastic (ABS) were employed. The following typical values of the material properties and the corresponding indices using equations (1) and (2) for the three materials are provided in Table 1. The units for M1 and M2 are cumbersome and not displayed.

Material	*E* (GPa)	*P* (Mg/m^3)	σ_y (MPa)	M_1	M_2
Steel	200	7.9	250	1.79	5.02
Aluminum	70	2.7	100	3.10	7.80
Plastic	3	0.9	40	1.92	13.00

Table 1 Material Indices for Various Materials

Figures 1 and 2 are obtained from Ashby [3]. In Figure 1 lines are drawn for M_1 passing through each of the three materials and parallel to the line $E^{1/2}/\rho = C$. In Figure 2 lines are drawn for M_2 passing through each of the three materials and parallel to the line $\sigma_y^{2/3}/\rho = C$.

From Table 1 and Figures 1, and 2 it becomes apparent that for minimum weight stiff beam bending, the materials steel and plastic behave nearly same way; however plastic seems to be superior than steel for minimum weight strong beam.

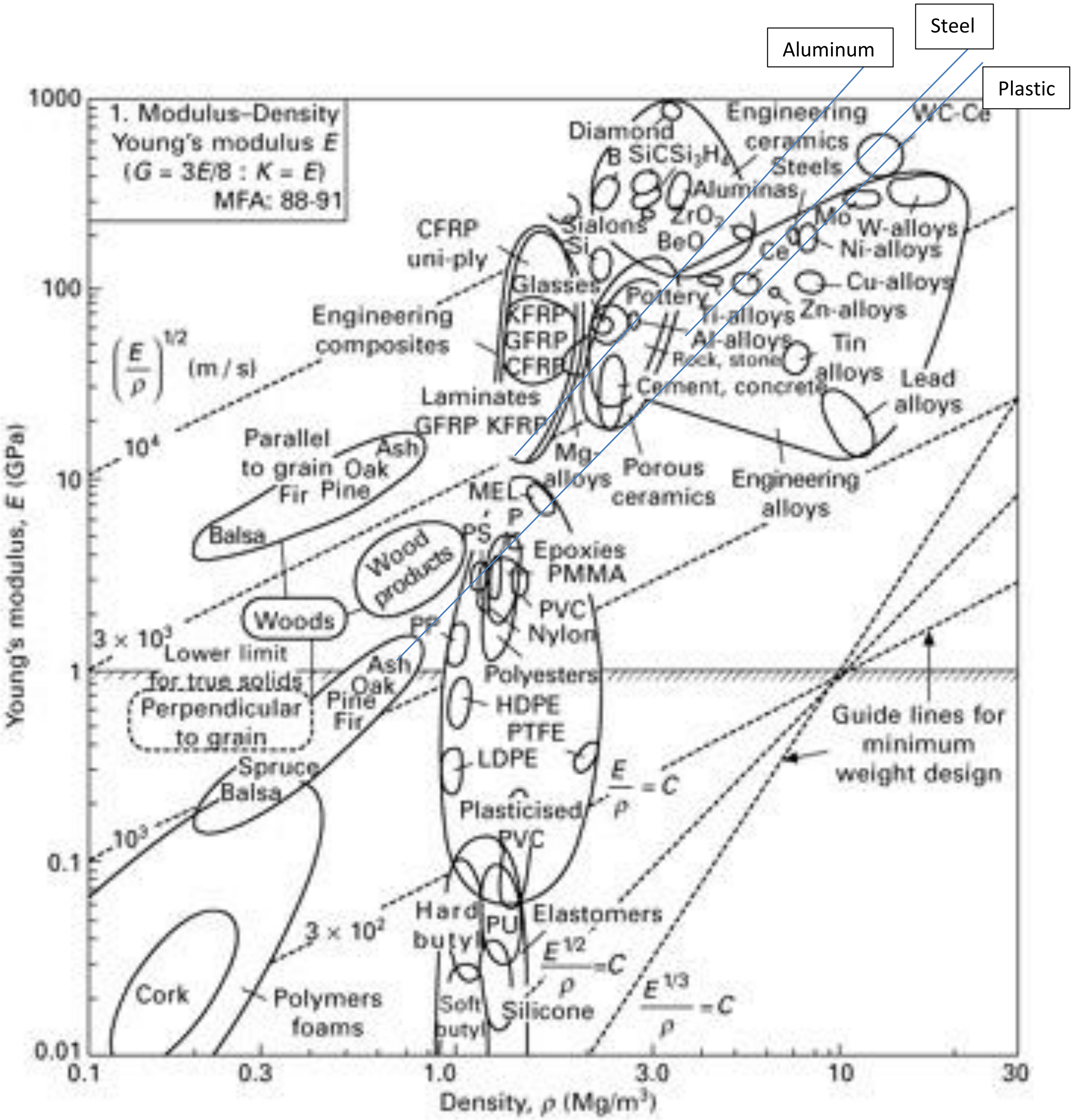

Figure 1 Young's Modulus, E plotted against Density, ρ

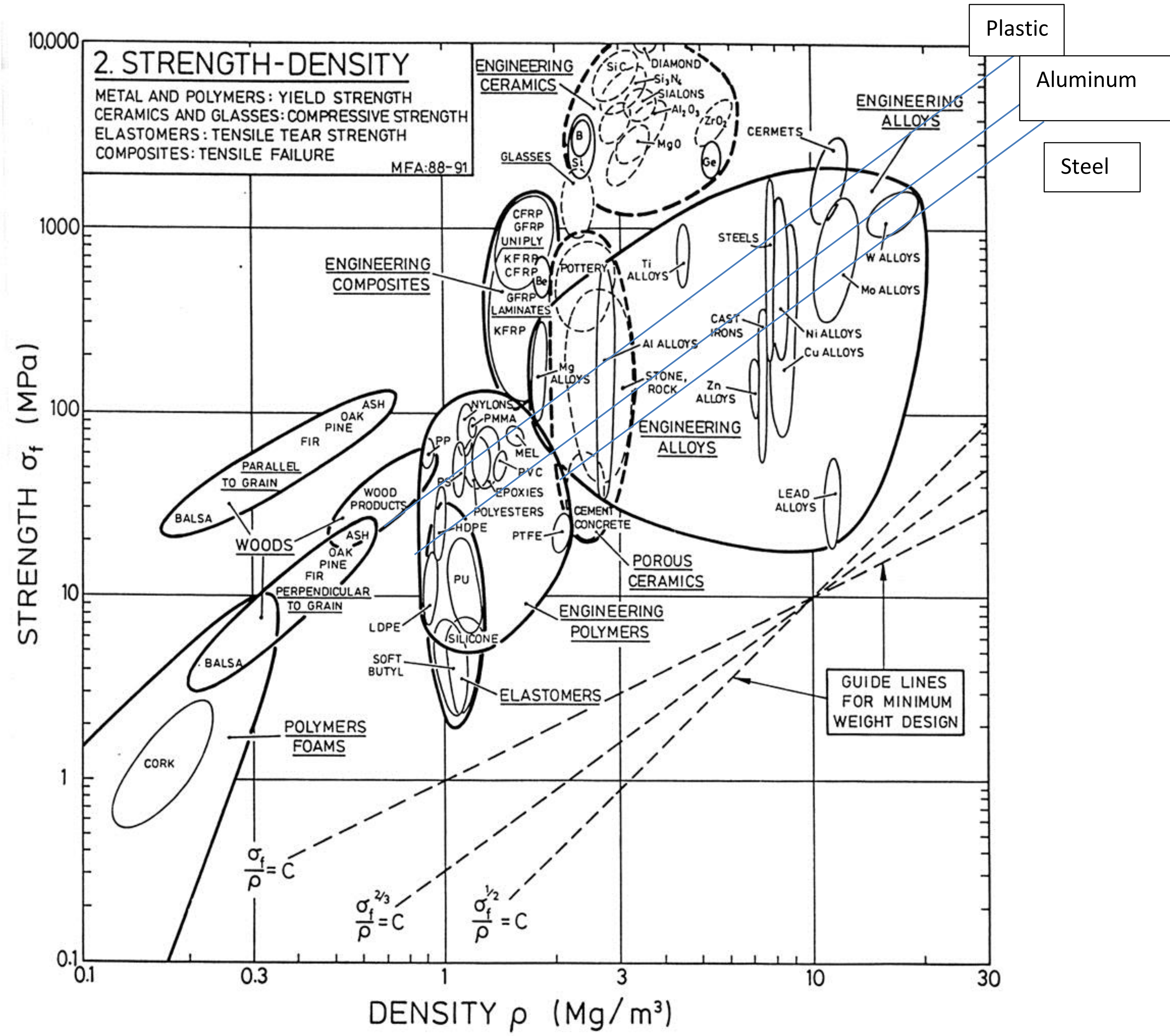

Figure 2 Strength, σ_y plotted against Density, ρ

The students in each group were required to work with all the component materials within their product to see how their materials compared with steel. This was one way of assessing the design optimization of the product analyzed. The students were asked to suggest alternate materials of construction, if they felt that optimization was not achieved.

INFLUENCE OF THE GLOBAL, ECONOMIC, ENVIRONMENTAL, AND SOCIETAL FACTORS ON THE REVERSE ENGINEERING PROJECTS

The four factors played an integral role in expanding the scope of product analysis. These factors individually or together in developing analysis prompt questions, as described below:

<u>Gate 1: Preparation and Initial Assessment</u>

(a) What were the key economic and global concerns at the time of development?
(b) What are the countries or regions where the product intended to be sold?
(c) What was the intended impact on the consumer and the society?

<u>Gate 2: Product Dissection</u>

(a) How does each of the factors influence the makings of the subsystem connections?
(b) Is the product intended to be disassembled? Why or why not?

<u>Gate3: Product Analysis</u>

(a) How the product was originally assembled?
(b) Recommend at least 3 design changes for the product addressing the concerns associated with the four factors. These changes should improve performance, serviceability, cost, etc.

ASSESSMENTS OF STUDENT PROJECTS IN TERMS OF MATERIALS SELECTION

A large number of products comprised the student projects. Some of these are reported here from the standpoint of material selection.

Radio controlled cars and helicopters were analyzed by a number of groups. Most of the components were made out of plastic; one group however concluded that some sort of steel could be used for added strength. Specifically one group working on RC helicopter wanted to change the material for the landing gear to aluminum from plastic, and that of the main shaft to stainless steel.

Nerf Guns were the products of choice for a large number of groups. Almost all these groups concluded that plastic was the adequate material for the product, although one group felt some metal and rubber parts could be used as well.

A few groups worked on electric drills where the shafts and gears were made out of steel, which they felt was the adequate material because of large stresses which resulted from torques they calculated from the power and rpm specifications. The housing and the insulation plate were made out of plastic because they were not load-bearing. One group working on Hitachi Drill mentioned that cast aluminum gear housing adds durability and dissipates heat efficiently.

The groups that worked on leaf blower and runaway alarm clock likewise felt that plastic was the adequate material for their products, The group that worked on vacuum brush roll, found a combination of metal and plastic parts, the metal parts bearing the large torsional shear stresses arising from their calculated values of torque from the wattage and rpm information.

The students were asked to treat the materials aspect the same way as is presented here. The loadings should be clearly understood and appropriate model should be used to derive the material indices. The students were expected to know how to use the material selection charts. We have presented only two charts (Figures 1 and 2) here for brevity.

However the most important objective of this activity was to develop a better appreciation of materials as it appears in the design process. Students were exposed to the software [3] which led to a rationalized process of materials selection. Furthermore this activity also helped them visualize how important is the materials selection in the overall design of a product.

DICUSSION

The activity mentioned in is work was a first attempt to include the aspect of material selection in the early engineering projects dealing with reverse engineering. These projects came from an introductory course on mechanical engineering practice. For the project part of the course, the students successfully disassembled and reassembled their products. The material selection aspect was a feature that was included in the latest offering of this course. There were some impediments that came up for including this feature in the student projects. One arose because of grossly inadequate materials background of the students at this level. Another one factor, although not overwhelming, was the inadequate background on computer aided design. The students were not equipped with the tools of solid modeling. An ideal reverse engineering process should include reproduction of the engineering drawings along with the bill of materials. This is currently an effort to change the sequencing of courses, along with the enhancement of come other courses. All of these modifications and enhancements should greatly help the instruction of this very important course.

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