Curriculum Development in Industrial Technology: Materials Science and Processes

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Abstract

The goal of Industrial Technology curriculum is to develop graduates that will enter the workforce with the best knowledge and skills or pursue further education having a strong background. In general, the curriculum requires students to take a materials course. Current practices in both metallic and nonmetallic materials fields have been either theoretical with very minimal practical application such as in Engineering programs or heavy on the practice oriented approach with very minimal theory as in Industrial Technology programs. Both theory and practice components are critical to the understanding and utilization of materials. A balanced combination of the two components in addition to utilization of software in material selection is highly recommended for the Industrial Technology Curriculum. Wood, as a material, will be used for illustration purposes. Any other material may be substituted as desired.

Introduction

Most Engineering programs and Industrial Technology programs require students to take some type of a "materials" course as shown in Table 1. A "materials" course may be basically theoretical with very little processing component or conversely may be a processes oriented course with minimal theory. In both cases, the course is intended to introduce to the student the behaviors of materials under applied conditions and to equip the graduate with ability to select and use materials intelligently. Each approach has its bias and can be defended fully in terms of depth and breath of content and conversely can be subjected to criticism.

Engineering	Industrial Technology
Strength of Materials I & II	Metallic Materials and Processes I
Engineering Materials Science	Metallic Materials and Processes II
Mechanics of Materials	Nonmetallic Materials and Processes
← Materials Selection →	

Table 1: Generic nature of course titles to be taken by students in respective programs

This paper suggests a comprehensive approach that incorporates both theory and practice interwoven with software for the ultimate materials learning experience. This approach may be used in the study of any material type and at any level of postsecondary education. It is assumed that the student can apply basic mathematical manipulations to solve a few problems and instructor can discuss formula components. Most institutions have the equipment related to materials study and only need minimal adjustment in curriculum to achieve this comprehensive approach. The paper presents a curriculum design used at Ohio Northern University. Three phases of materials study are chronologically presented including sample laboratory exercises and concludes with a material selection case study.

Phase 1 [1/5 time of the course]
The structure: A critical component of the materials study that educates about building blocks that include atom, cell, grain, and crystalline compositions and formations[1]. When the structure of materials is studied well, it can be used as a reference point in determining material behavior and selection. It is essential that students learn the composition of materials in preparation to becoming intelligent consumers and decision makers. When studying atomic theory, students will learn about atomic bonding that holds atoms together. The stronger the bond, the harder it is to separate. In studying cell structure for instance, they will investigate information of possible material hazards and also its affinity to degradation. In addition, the students will need to investigate grain size and shape because it reveals materials behavior based on whether it is short and brittle or long and ductile. Further, the student will investigate grain orientation and organization whether the material is amorphous or crystalline in a given state. Grain arrangement contributes significantly to materials behavior. Lastly, the student will study sample modified materials such as alloys, composites and woods to determine their difference in behavior. A typical modified material will have "desired characteristics" that justifies the investment. Software integration would enrich this study with its enormous bank of materials structure that can be easily accessed. The investigation in this phase will provide an understanding about the basic composition and arrangement of a material and will aid in intelligent selection of materials.

Example: Exercise # 1. Viewing materials microstructure cross-section. A Microscope with at least x100 magnification as shown in Figure 1 is a worth investing. The microscope is easily hooked up to a TV monitor (to accommodate larger audiences) and to interface with a computer using an adapter and a camera (to process the graphic image and print). A small plant may be uprooted and then cut into small specimens. A cross-section specimen of about 2-5 mm thick of a root, stem and branch should be made. A sharp object (knife or razor) is recommended to make a single cut without forming ridges. This single sharp cut will provide a

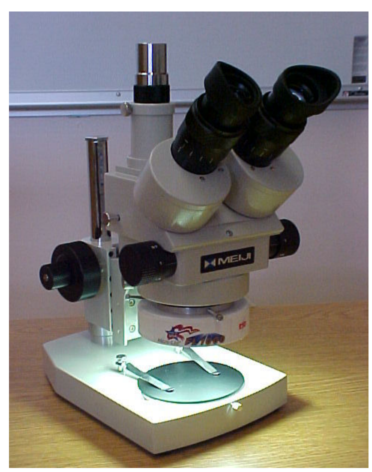

Figure 1: A microscope used in microstructure study

seamless and undistorted specimen to be studied under a microscope. When viewed properly, distinct parts will be identified such as lumen or vessels, early wood, late wood, heartwood, cambium, rays, etc. Discussion about the importance of microstructure parts in the formation of a tree that may be turned to lumber will arouse and keep student interest. Effects of cut patterns of a tree for lumber and its mode of drying will be greatly appreciated. A microscopic view may be made for softwood and hardwood specimens to reveal the amorphous nature of hardwood fibers as opposed to crystalline softwood fibers.

Exercise #2. Grain Direction. Lumber may be physically felt by hand to illustrate grain direction. Pass fingers lightly one direction on the longitudinal section of wood and then the other direction. One direction will reveal smoothness while the other will encounter roughness or high resistance. A planner may be used to demonstrate when wood is planned in one direction it is a smooth operation while chatter results when planned from the opposite direction.

Recommended Apparatus:

- A microscope with at least a x100 magnification. The MEIJI EMZ-5TR with a MA502 SWF 10X eyepieces is utilized here, Figure 1. It is enhanced with a camera that can be hooked up to a TV monitor for larger audiences to see and can be interfaced to a computer to customize graphics and print utilizing "Know Through Vision" software. The package cost is about $2500.00 and may be purchased at Dayton Microscope and Supply Inc. - www.daymic.com.
- A sharp cutting object for making a smooth cut such as a razor blade or a knife

Phase 2 [2/5 time]

The Properties: Internal composition of material structure will significantly influence its properties. The task in this phase is to examine material behavior. This paper presents materials as having mechanical and physical properties. Mechanical properties examination may include creep, ductility, fatigue, hardness, impact, and strength. Valuable information is derived from this study such as isotropic or anisotropic behavior of materials which helps determine material positioning relative to loading conditions. Physical properties examined could include density, electrical, magnetic, thermal and chemical. Corrosion could be used to study chemical properties. Several methods and equipment are utilized to investigate material property. Software integration would enhance investigation of properties with its comprehensive properties database of numerous materials that could lead to a comparison of similar or different material characteristics.

Example: Exercise # 1: Mechanical Properties- Compression Testing. Static and dynamic loading on materials is common and wood stands out (as a load bearing material) to be of interest because it is used widely in residential construction and is readily available. Clear wood specimens of 2” [50.8mm] x 2” [50.8mm] x 8” [203.2 mm] can be made and the tested for compression strength[2] using a Universal Testing Machine as shown in Figure 2. Multiple tests are ideal because more data yields better average results. Data resulting from the exercise (Table 2) is used to calculate stress, strain and the modulus of elasticity (E) as follows:

Figure 2: Universal Testing Machine

- Stress = Force(Loading) / specimen cross sectional area
- Strain = [Initial Length – Final Length]/ Initial Length
- E = Stress/Strain

Comparing calculated E values with those found in strength of materials tables in textbooks or internet indicate astonishing closeness. The student’s confidence is built by knowing how the empirical values found in the tables were derived and that they can be trusted.

Specimen	Cross-section Area (in^2)	Length Original (in)	Length Final (in)	Strain (in/in)	Applied Force (Lbs)	Stress (psi)	E ($x10^6$) (psi)
A	4	8	7 15/16	.0078	42,400	10,600	1.356
B	3 3/4	8	7 15/16	.0078	44,500	11,866	1.518
C	3 7/8	8	7 15/16	.0078	42,500	10,967	1.403
D	3 3/4	7 15/16	7 7/8	.0078	36,300	9,680	1.229

Table 2: Student results during Compression Testing of Cherry Wood in December, 2004. Empirical values[3] rate cherry wood to have an E of 1.49 x 10^6 psi.

Exercise # 2: Material Density. A simple physical experiment using a scale and graduated cylinder with water may be conducted to determine the density of hardwood and softwood. Make hardwood and softwood specimens of similar size and place them in a graduated cylinder containing water to determine displacement respectively. Compare exercise results with document empirical values. Data from the experiment can be used to calculate relationships between mass, volume and density.

Recommended Apparatus:

- A Universal Testing Machine – Tinius Olsen 60,000 LB Super "L" (Figure 2) is about $48,000.00. It is supplied by Tinius Olsen Testing Machine Co. Inc.
- Graduated cylinders or beakers may be purchased from chemistry and biological supplies such as Science Kit and Boreal Laboratories' cylinder - Pyrex, 10 ml x 0.1ml, double scale, economy, corning (4670402) is approximately $11.25..
- Scale – Ohaus Adventurer Balance (ARD110) is approximately $880.00 supplied by Ohaus company.

Phase 3 [2/5 time]
The Processes: This phase addresses the shaping of materials into products. At the beginning of this phase, students will have a fairly good theoretical base to predict reaction of particular material to a shaping process. The applications will help to cement their theory. Materials are subjected to numerous processing methods including material removal, forging, sheet-metal forming, joining, and casting. It is assumed that more exposure in processes in material manipulation leads to a wider experience in physical material behavior. Software integration will provide database of over 3,000 materials in selection and process at the student finger tips.

Example: <u>Exercise # 1: Drilling</u>. Wood specimens of 2" [5.08mm] thick are made and subjected to drilling using auger bits ranging from ½" to 3" at half inch intervals. This type of material removal introduces to the student a relationship between speed and amount of material finish. The "higher" the speed, the smoother the finish.

<u>Exercise # 2: Wood Lathe Utilization in Material Removal.</u> Wood could be placed on a wood lathe and turned to make cylindrical wood products. It will be noted that soft wood will behave differently from hardwood with respect to material removal. Given similar conditions, smaller pieces will be removed from hardwood than softwood. This exercise is intended to raise student curiosity that will lead to a meaningful discussion and understanding of such a process.

Recommended apparatus:

- Variety of wood processing equipment such as: wood lathe ($700), drill press ($500), auger bits ($100), clamps ($20). Quality and costs of such equipment vary and more information is available at websites such as: Sears.com, Homedepot.com, Lowes.com, and MSCdirect.com.

Software Integration
Case studies by Ashby and Cebon[4] and Ashby[5] entitled: "Materials for Table Legs" are adapted to present software usage and material selection process as follows:

Materials for Table Legs
A furniture designer would like to build a simple table: a flat sheet of toughened glass supported on slender, unbraced, cylindrical legs. The legs must be solid (to make them thin) and as light as possible (to make the table easier to move). They must support the table top and reasonable weight without buckling. What materials could one recommend?

Function	Column (support compressive loads)
Objective	Minimize mass Maximize slenderness
Constraints	Length L is specified Must not buckle Must not fracture if accidentally struck Cost of material is of interest, but not a constraint

Table 3: The design requirements

The Model: The design objectives in Table 3 are two fold, first weight is to be minimized and second slenderness is to be maximized. In addition, resistance to buckling is a constraint. First, consider minimizing weight.

A leg is a slender column of material with density ρ and a modulus of elasticity E. Its length, L , and the maximum load, P, it must carry are fixed by the design. The radius r of the leg is a free variable. We wish to minimize the mass m of the leg, given by the objective function:

$$m = \pi r^2 L\rho \tag{1.1}$$

subject to constraint that it supports a load P without buckling. The elastic load P_{crit} of a column of length L and radius r is

$$P_{crit} = \frac{\pi^2 EI}{L^2} = \frac{\pi^3 Er^4}{4L^2} \tag{1.2}$$

Where $I = \pi r^4 / 4$ is the second moment of area of the column. The load P must not exceed P_{crit}. Solving for the free variable, r, and substituting it into equation 1.1 gives

$$m \geq \left(\frac{4P}{\pi}\right)^{1/2} (L)^2 \left(\frac{\rho}{E^{1/2}}\right) \tag{1.3}$$

The material properties are grouped together in the last set of brackets. The weight is minimized by selecting the subset of materials with the greatest value of the material index

$$M_1 = \frac{E^{1/2}}{\rho}. \tag{1.4}$$

Now consider slenderness. Inverting equation 1.2 with P= P_{crit} and solving for r gives an equation for the thinnest leg which will not buckle

$$r = \left(\frac{4P}{\pi^3}\right)^{1/4} (L)^{1/2} \left(\frac{1}{E}\right)^{1/4}. \tag{1.5}$$

The thinnest leg is that made of the material with the largest value of the index

$$M_2 = E \tag{1.6}$$

Next, consider shock-resistance constraint: the legs must not fracture if accidentally struck. Shock resistance requires an adequate value of the toughness, $G_c = \frac{K_{IC}^2}{E}$, not merely fracture toughness, K_{IC}. A useful rule-of-thumb for this is to choose materials with a toughness, G_c, such that

$$G_c = \frac{K_{IC}^2}{E} \geq 1kJ/m^2. \tag{1.7}$$

Lastly, we need to bear in mind that cost is of interest.

Selection: Use software to seek the subset of materials which have high values of $\frac{E^{1/2}}{\rho}$ and E. Figure 3 shows the appropriate chart: Young's modulus plotted against density, ρ.

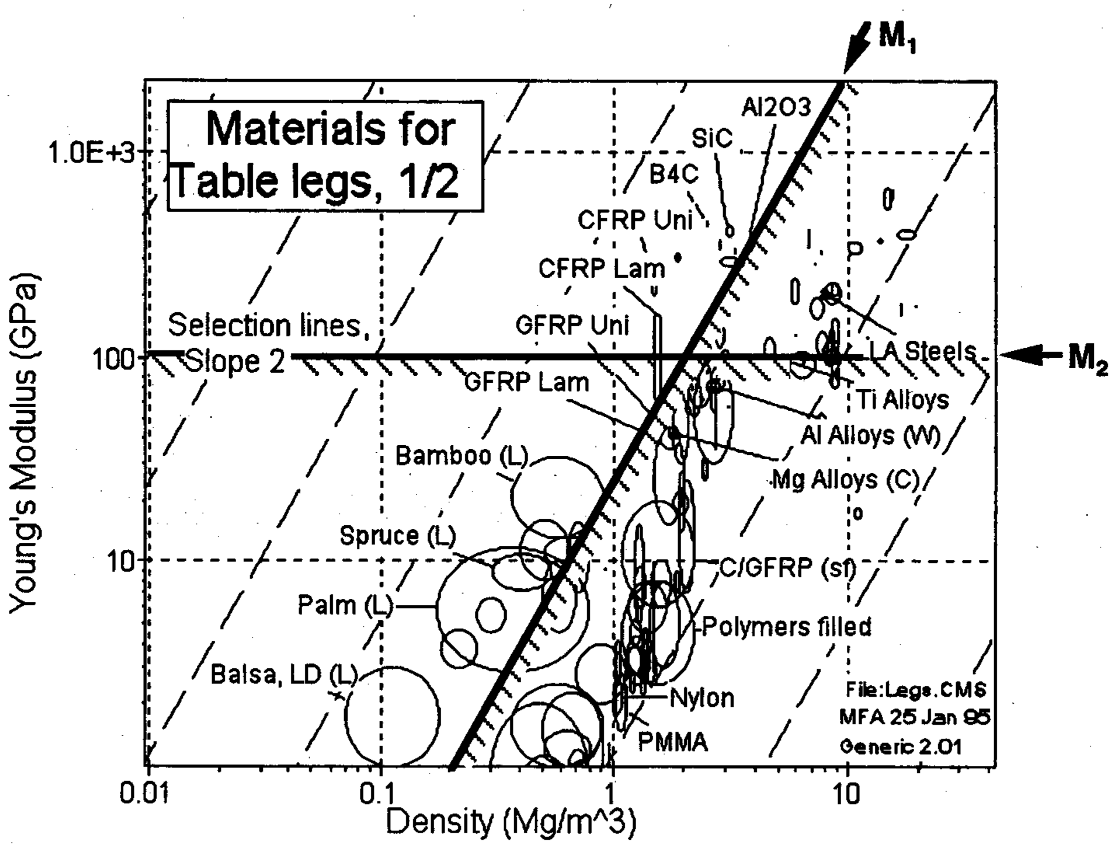

Figure 3: The Modulus – Density chart. The diagonal lines show the index M_1; the lines of M_2 are horizontal. Wood is a good choice; so is a composite such as Carbon fiber reinforced polymer (CFRP). Ceramics meet the stated design goals, but are brittle.

A grid of lines of slope 2 is drawn on the diagram, it defines contours of equal values of $\frac{E^{1/2}}{\rho}$. A selection line is positioned at $M_1 = 6GPa^{1/2}/(Mg/m^3)$. Materials above this line have high values of M_1. They include woods (the traditional material for table legs), composites (particularly CFRP) and certain special engineering ceramics. Polymers are not stiff enough and metals are too heavy. The choice is further narrowed by the requirement that, for slenderness, E must be large. A horizontal line on the chart at $M_2 = 100GPa$ eliminates woods and Glass fiber reinforced polymer (GFRP). If the legs must be slender, then the short list is reduced to CFRP and ceramics; if light (but not slender) then wood is good.

Table legs are exposed to abuse – they get knocked and kicked. Common sense suggests that an additional constraint is needed, that of adequate toughness. This is achieved by creating a chart with toughness, G_c, as one axis. In figure 4 the toughness is plotted against cost/kg, C_m. Putting a lower limit of $G_c = \frac{K_{IC}^2}{E} \geq 1kJ/m^2$ on G_c, but no limit on cost, identifies CFRP as the best choice for legs.

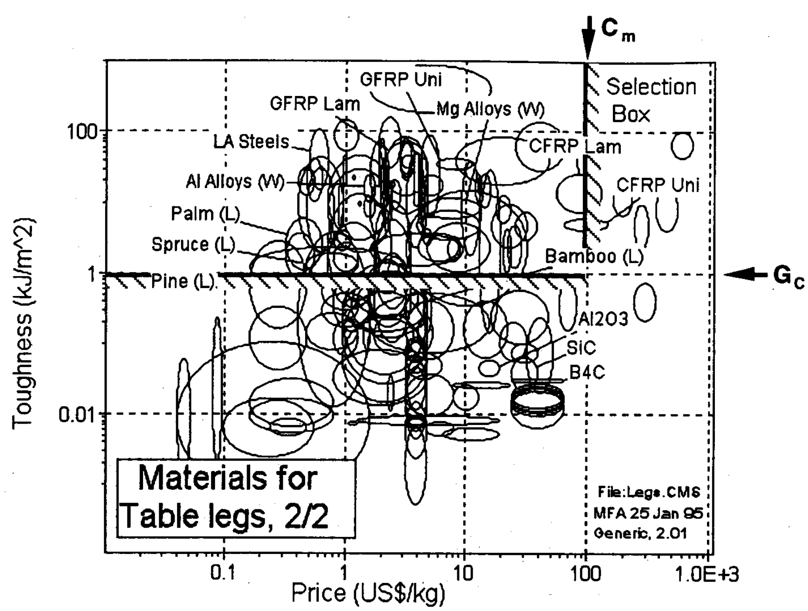

Figure 4: Showing material toughness with price comparisons

The cost of CFRP is high. If this was a constraint then by relaxing stringent conditions on M_1 and M_2, woods would become the best choice especially spruce, palm and pine. Table 4 shows materials and factors considered for this choice. The software is a powerful tool and will enhance critical thinking prior to decisions on material selection.

Material	M_1 $(GPa^{1/2}m^3Mg)$	M_2 (GPa)	Comment
Woods	5-8	4-20	Outstanding M_1; poor M_2. Cheap, traditional, reliable.
CFRP	4-8	30-200	Outstanding M_1 and M_2, but expensive
GFRP	3.5 – 5.5	20-90	Much cheaper than CFRP, but not as good
Ceramics	4-8	150-1000	Outstanding M_1 and M_2. Eliminated by brittleness.

Table 4: Materials for the table legs

The CES software cost is $3,300 for the first seat, discounted rate for more seats are available. Supplied by: sales@grantadesign.com

Conclusion

The experience in teaching materials using the comprehensive approach is very rewarding. Student interest is aroused and maintained as long as they see the relationship between the theory and application in the lab and real life. The students follow the phases with interest and are always eager to participate in hands-on activities. If placed in teams, the students learn not only the content but team work skills. One of the challenges is when and how to use the materials selection software. The software provides copious choices of materials with similar desired characteristics. The student will need to perform computations and then use the results to determine the best choice material. Students in Industrial Technology programs, with help from their instructors or other education resources, can develop the skills needed to compute desired characteristics to make better selections in a wider variety.

My students started out skeptic concerning the computational skills they needed to accomplish the selection of materials for the table leg. After discussions as to why it was advantageous to find other materials with similar characteristics, most students picked up the computational skills and performed well. The software needs patience and navigational skills to utilize effectively. During the entire learning process, students develop skills that will be beneficial to them while in college and at the workplace.

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Biography

Dr. John M. Mativo teaches Materials and Product Manufacturing courses at Ohio Northern University. His university teaching experience totals 10 years, six of which he served as chair of department of Technology at the University of Eastern Africa, Baraton. He holds a BA, BIT (Andrews, MI), BME (Auburn, AL), MED and Ed. D (Georgia) in Career and Technical Education. He is a member of Sigma Xi.