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ABSTRACT

A course in materials selection at the University of Florida is described. The course is designed to teach the student how to select materials for the construction of different types of engineering hardware and how to translate the operational requirements of engineering equipment into purchasing specifications. An outline of the course and sample problems are provided. (MLH)

MATERIALS SELECTION

Ellis D. Verink, Jr.

Rationale: Regardless of their engineering specialty, all engineers concerned with hardware of any sort (and this includes virtually all engineers) must deal constantly with the question of what material should be selected for construction of some particular piece of hardware. Except in trivial applications, it is not enough merely to indicate that the parts should be constructed of "steel" or "aluminum" or "plastic." Instead, the engineer must be skilled at focusing his engineering knowledge upon the design and operational requirements of a particular part so that they may be adequately translated into a purchasing specification for specific alloys, finishes, heat treatments, etc.

Due consideration must be given not only to the mechanical aspects of design, but also must include consideration of corrosion resistance, safety, product degradation, expected life, salvage value, appearance, equipment available for fabrication, joinability, effect on the environment, energy cost, availablilty of strategic materials, production capacity (for major applications), availability of replacement or repair materials on short notice, required rate of return on investment, depreciation practice, tax consequences, product liability considerations, etc.

The process can be exceedingly complex. However, it is amenable to organization into a generalized methodology which can simplify the process greatly.

The Course in Materials Selection at University of Florida

Objectives: After completing this course students should be able to

1. Apply metallurgical and design principles to the solution of materials selection problems through use of a generalized methodology.
2. Defend materials selections effectively both orally and in written form.
3. Select and use appropriate industrial literature in the solution of materials selection problems.
4. Select and use appropriate library resources.

Prerequisites: First course in materials and/or permission of the instructor.

Students: Juniors and Seniors in Engineering. The course is required for students in Materials Science and Engineering and elective for other disciplines. Class size ranges from 15-25, about half of which are undergraduates in MSE. A number of graduate students also elect this course.

Method of Presentation: This three credit course is conducted in the lecture and discussion mode. Lectures are scheduled twice a week. Two hours are available for each meeting, although the average contact time per class is 1 1/2 hours (equivalent to 3 one-hour classes per week). The final grade is based on homework problems (40%), Midterm Examination (30%) and Term Paper (including Oral Presentation) (30%). There is no final examination. The lecture schedule and reading list are attached as appendices. Also attached are examples of typical homework problems. Attendance is not mandatory, however penalties are assessed for late work.

The philosophy of the lectures is to review particularly pertinent metallurgical and materials principles, most of which are familiar to metallurgical and ceramics students, but are less so to students from other disciplines. Many examples are presented to illustrate the direct connection between these principles and the use characteristics of materials. The homework problems are designed to reinforce the lecture material. They also are designed to "force" the students to become acquainted with library information and industrial literature. All too often students are reticent to refer to industrial publications either through ignorance of the availability of such material or through suspicion. Students are supplied with complimentary copies of a number of the industrial references shown in Table I. These are directly useful in working the homework assignments.

Background: Clauser et al(1) have reviewed the overall process of materials selection in a series of short articles combined under the general title "How Materials are Selected." As Clauser points out the task of making a sound, economic choice of engineering materials is not an easy one but is nonetheless one of the most important requisites to the development and manufacture of satisfactory parts at minimum cost. While there is a huge and growing literature on materials and their general application, there often is a lack of complete facts on which to operate when making specific choices.

Until the last two decades, materials selection was largely a matter of past experience, and engineers tended to make everything out of the few materials with which they were familiar. This practice continues today, however there is an increased awareness of the inadequacy of this practice. The tremendous increase in the variety of materials, together with the need to accommodate new and more severe service, ecological and energy requirements at minimum cost, have forced the development of a rigorous engineering approach to materials selection. The recent history of ever-mounting awards in products liability lawsuits adds another important consideration when choosing materials of construction.

The Selection Process

The so-called "scientific method" lists the major steps in the solution of engineering problems. They include

1. Analysis of the problem
2. Formulation of alternative solutions
3. Comparison and evaluation of alternatives
4. Decision.

In the context of materials selection these steps become

1. Defining the functional and service requirements of the materials of construction
2. Narrowing the field of choice to a few candidate materials
3. Comparing and evaluating the candidate materials
4. Making the final choice.

Defining the Materials Requirements

At this stage in the process it is essential to identify and define the specific functions which are to be performed. What is the part supposed to do? The practices of "Value Engineering"(2,3) have broad application in this process. The detailed functions need to be identified carefully. For example, an automotive exhaust system performs a number of functions including

1. Conducting engine exhaust from the engine
2. Reducing noise
3. Preventing noxious fumes from entering the automobile
4. Cooling the exhaust
5. Reducing exposure of body parts to corrosive vapors and gases
6. Several others.

The providing of these functions imposes special materials requirements, including

1. Resistance to corrosion by CO, CO_2, SO_2, H_2SO_4 (from catalytic converter), H_2O, Pb, Br in the exhaust vapors
2. Resistance to corrosion by atmosphere, road salts, mud, etc., at various temperatures
3. Ability to be formed into intricate shapes
4. Weldability and ease of assembly
5. Availability in large quantities
6. Relatively low cost
7. Ability to be coated (for some alternatives)
8. Others.

Selecting of Candidate Materials

The problem of selecting candidate materials becomes a matter of evolving a basis for narrowing the field of choice from the thousands and thousands of potential choices, to the relatively few (three or four at the most) actual candidate materials.

To do this it is necessary to translate the functional and materials requirements into materials property terms.(6) This implies a need for an inventory of materials properties.

A number of technical societies, trade associations, journals, and industrial firms have responded to the need. For example, the American Society for Metals has made an outstanding contribution with the publication of its new series of METALS HANDBOOKS. Table I is a partial list of "resource references" the author has found particularly useful in conducting the course in Materials Selection at the University of Florida. The list grows each year.

For parts subject to uniaxial tension it is simple to connect tabulated data to functional requirements since tensile strength data are readily available. However, for many actual service conditions there is no direct or simple correspondence with tabulated materials properties, and considerable creativeness is required in establishing a data base with which to evaluate and compare materials.(4,5) Often it is helpful to combine tabulated properties for the sake of comparison, e.g., strength/density ratio, $/psi T.S., etc. Figure 1 shows some typical formulas based on cost for performance.

In the case of the exhaust system, above, considerable tabulated information exists, for example,

1. Corrosion data for metals and ceramics in the presence of exhaust gases
2. Weldability data for metals
3. Formability data, e.g., bend radii, etc.
4. Price information
5. Availability information
6. Mechanical properties at various temperatures.

From this data it is relatively simple in the case of the exhaust system to narrow the choice down to three or four materials which can then be compared in minute detail and the choice can be optimized in accordance with manufacturing, marketing or other objectives.

For complex systems weighted performance indices have been employed. When used with care such indices can be very helpful since each individual property can be weighted in accordance with its importance. NASA developed such a weighted index for use in selecting materials for the SST,(1) Figure 2. The processes of selection are amenable to computerization where the cost justifies.

Term Project

Each student selects a term project from a list of major projects. Table II is the list of projects used during the Spring Quarter of 1975. Students are asked to prepare a "Report to Management" and an oral presentation covering the topic of their choice. The student presentations are given during the final week of classes. Each student has a maximum of 10 minutes for his presentation (including interruptions and questions). The rationale is that presentations to management seldom permit more than 10 minutes to present the subject matter for decision. This forces students to organize their information carefully and provides experience in effective presentation. Students are urged to use slides, flip charts, hand samples, etc., and are given individual assistance in preparation of these aides if they request it.

Student Response

Students usually consider that the amount of work necessary for this 3-credit course is higher than for many 3-credit courses. Nonetheless, it is one of the two most popular elective courses within the Department. The mechanical and chemical engineers in particular tend to elect this course.

It is usual to find that certain of the students are "unnerved" early in the course. Apparently undergraduates are not accustomed to problems the answers to which represent engineering compromises. The students with the highest grade point averages seem to be particularly uneasy when there is not one unique answer to a homework problem. By the third or fourth problem such students seem to "get in the swing of it" and begin to relish the opportunity to exercise their own individuality, and by the finish of the course these are usually the most enthusiastic students.

Conclusion

Engineers cannot avoid the need to make intelligent selections of materials of construction. A course designed to couple fundamentals of material science to the solution of practical problems presents an appropriate vehicle not only to illustrate the close connection between structure of materials and their properties of engineering importance, but also to incorporate the professional considerations which are so important to the education of engineers for practice.

Acknowledgement

My particular thanks are given to Dr. F. N. Rhines, then Chairman of the Department of Materials Science and Engineering at the University of Florida, for his encouragement to me in the development of the course in Materials Selection. I also wish to acknowledge a number of particularly useful discussions with Dr. John Wood of Lehigh University who has taught a similar course for a number of years.

References

1. H. R. Clauser, R. J. Fabian and J. A. Mack, "How Materials are Selected," Materials in Design Engineering, July 1965, pp. 109-128.

2. D. Miles, Techniques of Value Analysis and Engineering, McGraw-Hill, New York, 1961.

3. Handbook of Value Engineering, Office of Assistant Secretary of Defense (Installations and Logistics), Washington, D. C.

4. H. J. Sharp, Engineering Materials, American Elsevier Publishing Co., New York, 1966.

5. Engineering Case Library, Stanford Engineering Case Library, Palo Alto, California.

6. M. G. Busche, "Mechanical Properties and Tests/A to Z," Materials Engineering, June 1967.

TYPICAL FORMULAS BASED ON COST FOR PERFORMANCE*

Type of Structure and Loading	Relative Cost for:	
	Equal Strength	Equal Stiffness
Rectangles in Bending	$\left(\frac{YS_1}{YS_2}\right)^{1/2} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$	$\left(\frac{E_1}{E_2}\right)^{1/3} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$
Solid Cylinders in Bending	$\left(\frac{YS_1}{YS_2}\right)^{2/3} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$	$\left(\frac{E_1}{E_2}\right)^{1/2} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$
Solid Cylinders in Torsion	$\left(\frac{YS_1}{YS_2}\right)^{2/3} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$	$\left(\frac{G_1}{G_2}\right)^{1/2} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$
Solid Cylinders in Tension	$\left(\frac{YS_1}{YS_2}\right) \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$	$\left(\frac{G_1}{G_2}\right) \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$
Solid Cylinders as Columns	—	$\left(\frac{E_1}{E_2}\right)^{1/2} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$
Cylindrical Pressure Vessels	$\left(\frac{YS_1}{YS_2}\right) \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$	—

*YS = yield strength, psi; E = Young's modulus, psi; ρ = density, lb/cu in.; P = price, $/lb.

Figure 1

WEIGHTED INDEX RATING CHART FOR SST MATERIALS

MATERIAL	GO-NO-GO * SCREENING			RELATIVE RATING NUMBER (○ RATING NUMBER X "WEIGHTING FACTOR)								MATERIAL RATING NUMBER
ALLOY AND CONDITION	CORROSION	WELDABILITY	BRAZABILITY	STRENGTH (5)"	TOUGHNESS (5)	STIFFNESS(5)	STABILITY (5)	FATIGUE (4)	AS WELDED STRENGTH (4)	THERMAL STRESS (3)	COST (1)	$\frac{\Sigma \text{ REL RATING NO.}}{\Sigma \text{ SIGMA RATING FACTORS}}$
RENE 41												
A286												
INCONEL W												
WASPALLOY												
L605												
D979												
M155												
V36												
INCO 718												
INCO 901												

"WEIGHTING FACTOR (RANGE = 1 POOREST TO 5 BEST)

○ RANGE = 1 POOREST TO 5 BEST

* CODE = S = SATISFACTORY
U = UNSATISFACTORY

Figure 2

MSE-422 - MATERIALS SELECTION

Lecture Schedule

Part I	Introduction	Reading
	Lecture 1: Sources of Information Philosophy of Material Selection Value Analysis	
	Selection of Ferrous Materials	
	Lecture 2: Fabrication as a basis for selection. Choice of steels on basis of economy of manufacture. Yield strength at minimum cost	Ref 4, 111-122 179-216 290-301 319-335
	Lecture 3: Hardenability of steels as a basis for choice Problem #1 due	Ref 9, 148-169 Ref 10, All
	Lecture 4: Selection of steels for fatigue resistance, effect of composition, hardness gradients, surface condition, flow lines, notch toughness Problems #2, #3 due	Ref 4, 63-111 217-243 316-319
	Lecture 5: Preliminary heat treatment for machining and forming of steel	Ref 4, 302-316 Ref 5, 1-66 Ref 6, 1-101 Ref 7, 1-144
	Lecture 6: Final heat treatment of steels for service Problem #4 due	Ref 1, 607-644
	Lecture 7: Surface hardening of steels, carburizing, nitriding, induction hardening and tempering, flame hardening Problem #5 due	Ref 2, 124-133 Ref 3, 107-150 Ref 5, 124-126
	Lecture 8: Tool and die steels, selection of tool materials for cutting, blanking, drawing, forging, extrusion, rolling. Heat treatment of tool steels Problem #6 due	Ref 4, 637-659 671-778 Ref 5, 221-242 Ref 7, 69-77 145-157 194-200 Ref 14, All Ref 15, All
	Lecture 9: Iron and steel castings. Selection and heat treating of cast irons Problems #7 and #8 due	Ref 2, 46-51 109-114 Ref 3, 21-36 Ref 4, 122-146 349-406 Ref 5, 203-220 Ref 8, 335-380

Part III Selection of Non-Ferrous Materials

		Reading
Lecture 10:	Selection of aluminum alloys Alloy designations, heat treatment, advantages and limitations	Ref 4, 866-959 Ref 5, 271-283 Ref 13, 109-139 Ref 16, 269-336 675-684
Lecture 11:	Selection of copper base alloys Selection of nickel alloys Problems #9 and #10 due	Ref 4, 960-1052 1113-1130 Ref 5, 284-292 297-300 Ref 13, 89-107 141-172 Ref 16, 337-357 366-374 685-702
Lecture 12:	Selection of stainless steel High temperature materials Problems #11 and #12 due	Ref 4, 407-636 Ref 13, 45-89 Ref 16, 245-295 663-674

MIDTERM EXAMINATION Evening Over material to date

Part IV Failure Analysis

Lecture 13:	Analysis of service failures caused by fatigue, corrosion, etc. Products liability	Ref 1, 243-254 Ref 2, 97-103 Ref 11, 91-109
No Class		
Lecture 14:	Fracture toughness as a basis for materials selection	Handout material
Lecture 15:	Effect of wear, siezing and galling, residual stresses, prestressing	Ref 1, 216-222 Ref 2, 91-96 104-108 Ref 3, 89-96 Ref 4, 244, 257
Lecture 16:	Economics, materials selection in the Process Industries Oral presentations of student projects.	

NO FINAL EXAM

References

1. Metals Handbook, 1948 edition, ASM.
2. Supplement to Metals Handbook, Metal Progress, Vol. 66, No. 1A, July 15, 1954, ASM.
3. Supplement to Metals Handbook, Metal Progress, Vol. 68, No. 2A, August 15, 1955, ASM.
4. Metals Handbook, Vol. 1, Properties and Selection of Materials, 1961, ASM.
5. Metals Handbook, Vol. 2, Heat Treating, Cleaning and Finishing, 1964, ASM.
6. Metals Handbook, Vol. 3, Machining, 1967, ASM.
7. Metals Handbook, Vol. 4, Forming, 1969, ASM.
8. Metals Handbook, Vol. 5, Forging and Casting, 1970, ASM.
9. "Modern Steels and Their Properties," Bethlehem Steel Corporation, Bethlehem, Pennsylvania.
10. "Atlas of Isothermal Transformation Diagrams," United States Steel Corporation, Pittsburgh, Pennsylvania.
11. Corrosion Engineering, Fontana and Greene, McGraw-Hill Book Company, 1967.
12. Protective Coatings for Metals, Burns and Bradley, Rheinhold Publishing Company.
13. "Methods of Materials Selection," Verink, Editor, Gordon and Breach, 1968.
14. "The Tool Steel Trouble Shooter," Bethlehem Steel Company.
15. "Tool Steel Simplified," F. R. Palmer and G. V. Luerssen, The Carpenter Steel Company, Reading, Pennsylvania.
16. Metals Handbook Vol. 6, Welding and Brazing, 1971, ASM.
17. Metals Handbook, Vol. 7, Atlas of Microstructures, 1972, ASM.
18. Metals Handbook, Vol. 8, Metallography Structures and Phase Diagrams, 1973, ASM.
19. Metals Handbook, Vol. 9, Fractography, Atlas of Fractographs, 1974, ASM.
20. Source Book in Failure Analysis 1974, ASM

MSE 422 - SELECTION OF MATERIALS

Project Topics

1. The hull material for a floating Nuclear Power Plant.
2. Sheathing and Protection System for a transatlantic cable.
3. Hull material for a high speed aquatic transportation vessel for commuters in the New York-Newark area.
4. Hydraulic brake system for an interstate bus.
5. Materials of construction for a 50 ft. diameter X 30 ft deep "display tank" for Marineland. (Need visibility through sidewalls as well as at top.)
6. Liquified natural gas (LNG) tanks for an ocean-going tanker.
7. Materials for a 1,000 ft tall TV tower.
8. High pressure piping for a super-critical steam power plant.
9. Material for beer cans.
10. Forty-two inch diameter trans-Canada pipeline bringing oil from Alaska to U.S. mainland.
11. 5,000 Gallon capacity, highway transportation vehicle for liquid hydrogen.
12. Highway transport vehicle to carry 7.5 tons of molten aluminum from an aluminum reduction plant to a casting plant 45 miles away.
13. Construction of a 11,000 ft runway to accommodate the English Concorde, supersonic aircraft.
14. A cooling system for temperature control during curing of concrete for a 1 million KW dam.

MSE 422

MATERIALS SELECTION

Homework Problem #9

In the extrusion process the "circle size" is important since it "specifies" the minimum die opening and hence the minimum extrusion press size which may be considered. Assume that the following jobs are not limited by the hydraulic pressure available, but only by the circle size of 8". Indicate, using sketches where appropriate, minimum radii, critical tolerances, etc. Also show how you would minimize cost (maximize production) in the production of the following aluminum extrusions.

a) Residential window frames.

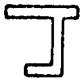

Figure 1

b) An integrally stiffened, heavy duty, interlocking floor for a highway van trailer.

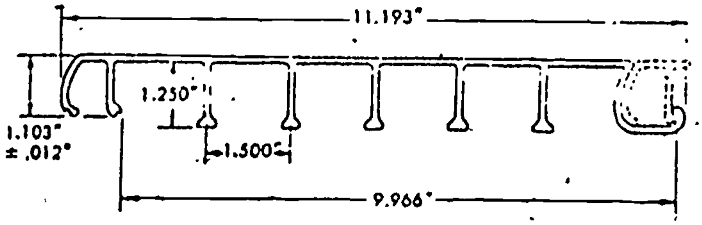

Figure 2

c) What alloy(s) would you select for a and b above. Give details of heat treatment.

Problem 1

Consider the Fabrication of a sheet steel front fender for an automobile.

(a) The configuration of the finished part requires special procedures to permit its manufacture as a stamping. Without such procedures it is doubtful the part could be manufactured from sheet. What manufacturing steps would you specify, and why?

(b) In the vicinity of the headlamp, the metal(.036" thick) is stretched 27% based on grid measurements. How should the metal be ordered from the mill? Would you purchase remined semi-killed or killed? What grain size? Give reasons.

(c) Prior to shipment from the mill the sheet is roller leveled. Why? After receipt of the material, a major strike shut down manufacturing operations for 156 days. When the plant started up again new fenders would not pass inspection. Noticeable surface irregularities were evident which had a "wormy" appearance. Explain what had happened and indicate what corrective measures should be taken.

(d) If a pebbly, rough surface developed during manufacturing, what is the likely cause of the trouble?

(e) What surface finish (roughness) should be selected? Why?

MATERIALS SELECTION

Problem #4

Describe the method of manufacture you would select for shaping each of the following parts. Give complete fabricating schedule. For example, if a forging; specify type, i.e., press or drop; if a casting...what melting methods, temperature and precautions in melting, alloy, etc. If joining is required indicate method, temperatures, materials, etc. If powder metallurgy is specified...powder size, type, sintering time and temperature, pressure, etc.

(a) An aircraft landing wheel for the C-5a.
(b) A toothpaste tube
(c) The yoke for an automobile universal joint
(d) An 8-cup coffee pot
(e) A self-lubricating bearing for a small motor
(f) A picnic cooler

MSE 422

MATERIALS SELECTION

Problem #8

a. What are the functional requirements for the tool steels in thread rolling dies?

Select a tool-steel for roll-threading mild steel bolts. Justify your choice.

b. It is desired to perforate 1/8" thick cardboard in one stroke. The finished cardboard is to be 8" x 10" and have 1500 holes, 5/32" diameter which are to be arranged in a square pattern.

In this case a one-piece die two inches thick must be used. Specify the tool steel for the die. Pick the steel for the punches. Defend your choices.