ME349
Engineering Design Projects

Introduction to Materials Selection

The Material Selection Problem

Design of an engineering component involves three interrelated problems:

(i)   selecting a material,
(ii) specifying a shape, and
(iii) choosing a manufacturing process.

Getting this selection right the first time by selecting the optimal combination your design has enormous benefits to any engineering-based business. It leads to lower product costs, faster time-to-market, a reduction in the number of in-service failures and, sometimes, significant advantages relative to your competition.

But to realize these benefits, engineers have to deal with an extremely complex problem. There are literally tens of thousands of materials and hundreds of manufacturing processes. No engineer can expect to know more than a small subset of this ever-growing body of information. Furthermore, there are demanding and shifting design requirements such as cost, performance, safety, risk and aesthetics, as well as environmental impact and recycle-ability. This document is meant to provide an introduction to the material selection process.

Material Selection

The basic question is how do we go about selecting a material for a given part? This may seem like a very complicated process until we realize than we are often restrained by choices we have already made. For example, if different parts have to interact then material choice becomes limited.

When we talk about choosing materials for a component, we take into account many different factors. These factors can be broken down into the following areas.

Material Properties
       The expected level of performance from the material

Material Cost and Availability
       Material must be priced appropriately (not cheap but right)
       Material must be available (better to have multiple sources)

Processing
> Must consider how to make the part, for example:
>> Casting
>> Machining
>> Welding

Environment
> The effect that the service environment has on the part
> The effect the part has on the environment
> The effect that processing has on the environment

Now clearly these issues are inter-linked in some fashion. For example, cost is a direct result of how difficult a material is to obtain and to machine. And the effect of the environment on the material is clearly related to the material properties.

So if we really want to use a novel or unusual material, the choice must be made early in the design process. Then we can do the detailed design work using the correct material properties.

Consider the example of wooden airplanes and metal-framed airplanes. If we were to design an airplane of either material we will have to make the choice early. The end designs are quite different. So, the material choice can radically alter the final design. But the possibility also exists that it may not. After all what is the real difference between a 1045 and a 1035 carbon steel?

Kinds of Materials   (What kind of materials can I use?)

Metals
> Iron
> Aluminum
> Copper
> Magnesium

Composites

Ceramics
> Glass
> Semi-conductors
> Structural ceramics (SiN, SiC)
> Refractory Composites

Polymers
> Rubber
> Plastics

Liquids

Gases

As mechanical engineers we deal mostly with metals. Metal properties tend to be well understood and metals are somewhat forgiving materials. We can make small mistakes (sometimes big ones) and get away with a poor design as a result of metal's forgiving nature. We see ceramics and composites all around us, but they tend to be used in special applications because of fabrication costs. This however, is changing. Plastics are among the most common modern material choices. In large volume production, plastics are inexpensive. In small volume productions, plastics can be an extremely expensive choice due to high tooling costs.

Material Properties

As mechanical engineers we are most concerned with characteristics such as:

> Mechanical Properties
> > Strength
> > > Yield Strength
> > > Ultimate Tensile Strength
> > > Shear Strength
> > Ductility
> > Young's Modulus
> > Poisson's ratio
> > Hardness
> > Creep
> > High or low temperature behavior
> > Density
> > Anisotropy
>
> Fatigue strength
>
> Fracture Toughness
>
> Thermal Properties
> > Thermal expansion coefficient Thermal conductivity
> > Specific heat capacity
>
> Magnetic Properties
>
> Fabrication Properties
> > Ease of machining
> > Ease of welding, casting, etc
> > Hardening ability
> > Formability
> > Availability
> > Joining techniques

Environmental Properties
       Corrosion properties
       Toxic effects
       Out-gassing properties

Gas and Liquids
       Viscosity

However, numerical properties to represent these properties are not easy to find. We would like all this information at our fingers, but it takes some digging. In some cases, objective data does not exist. There is no single, standard place to go and look for all this information. We can however make some recommendations.

You can get good information on particular materials from Standards handbooks, such as the *ASM's Books on Metals*. You can obtain information on gases and liquids from *CRC's Handbooks*. And the best place to get information on plastics and composites is from the manufacturer. Web sites are also beginning to offer good information. Check the websites on the course web page for material property information and help in the selection process.

The choice of a material is frequently the result of several compromises. For example, the technical appraisal of an alloy will generally be a compromise between corrosion resistance and several other properties such as strength and weldability. And the final selection may come down to a compromise between technical and economic factors. In identifying a material, approach the task in three stages:

List the material requirements for the design. Use the list of characteristics given above to help you in defining ALL the critical requirements. Rank the requirements in importance to the design's success.*

Select and evaluate candidate materials. By researching the various handbooks and resources, attempt to rank your candidate materials as to how well they meet the requirements. Use a decision table to identify the best choices.

Choose the most economical material. Research material costs and production costs based upon your anticipated production run. Choose the least expensive of your best choice candidate materials.

* We would like to know how to rank and select materials. Consider the airplane problem mentioned earlier. In that case we would like a material that is stiff yet light. What could we do to help arrive at an appropriate material choice? How could we create some numerical standing that would help us compare one material with another?

The following procedure is taken from *Material Selection in Mechanical Design* by Michael Ashby. This text is available electronically using KNOVEL. See Chapter 5 for the basic procedure.

Four Basic Steps

1) Translation: express design requirements as constraints and objectives

2) Screening: eliminate materials that cannot do the job

3) Ranking: find materials that best do the job

4) Supporting Info: handbooks, expert systems, web, etc.

Step 1) Translation

Function: What does the component do?

Objective: What essentials conditions must be met?

Constraints: What is to be maximized or minimized?

Free Variables: Identify which design variables are free?

Example: Tie Rod

Function: Support a tensile load
Objective: Minimize mass
Constraints: Required length
*   Load carrying capability w/o/ failure*
Free Variables: Cross-sectional area
*   Material*

m = A*L*Density
F/A < Yield Stress

Eliminate free variable

m >= (F)(L) (Density/Yield Stress)

therefore minimize weight by maximizing

Yield Stress / Density

Step 2) Screening

Methods to evaluate large range of materials

Material Bar Charts

[Material Property Charts](#) (density vs. Young's Modulus)

Screen on Constraints

Rank on Objectives

Step 3) Ranking

What if multiple materials remain after screening?

Rank on Objectives

Objectives define performance metrics

Step 4) Select, then verify with any supporting materials