Materials Selections and Product Prototyping:
Unit 3

Topics

1. Material selection processes for high-fidelity prototypes, Prototyping Materials,
2. Modeling of Material Properties,
3. Modeling and Design of Materials and Structures

- Why is material selection important?
- Is there any place where guidelines are published for prototype material selection?
- Are there nontraditional materials that can be used for prototyping?
- Are there procedures to select a material for a prototype?
- Where to find resources for the properties of different materials?

Prototyping Material Properties

- When selecting a material, material properties are critical since they are the link between basic material composition and service performance.
- Material processing is also critical since it determines part manufacturing processes.
- Prototyping materials often are different than the final product materials, especially for lower fidelity prototypes, due to the differences in project objectives and time constraints in prototyping.
- For quick prototyping purposes, there are several materials available.

Quick prototyping materials

- Modeling clay
- Machining wax
- Foam board
- Foam core
- Rubber, elastomer
- Cardboard, paper, cloth

Quick Prototyping Materials

- ***Modeling clay:*** It is easy to work with, is useful for visualization and airflow studies, always remains soft, and is available in craft shops. *For example; each time US Congress authorizes a new coin or medal, an artist sketches out ideas for the design. After one design has been approved, the U.S. Mint sculptor engraver sculpts a clay model as shown in Figure below.*

Prototyping Materials

- ***Machining wax***: Wax can be machined well and is useful for prototyping tooling patterns.

- ***Foam board***: As shown in Figure, foam board has a good finish, is easily carved, useful for painting (aesthetic & appearance models), and machinable. Foam is available can be cut and formed with a knife.

Prototyping Materials

- ***Foam core***: The foam core is made of sheets of hard paper with internal foam, is useful for mock-ups and layout of square objects, can be used with clay for more complex shapes, and is more durable and rigid than cardboard.

Prototyping Materials

- ***Rubber, elastomer***: As shown in Figure below, rubber and elastomer are useful in energy absorption applications or seals, can be used as a removable mold for castings of other materials, and can be carved.

- ***Cardboard, paper, cloth***: Cloth and paper can serve as joints in mock-ups and are very cheap.

Material Selection for High-Fidelity Prototypes

- **The previous section summarizes some commonly used prototyping materials. However, these materials are normally used for lower fidelity prototypes.**
- When selecting materials for higher fidelity prototypes, it sometimes helps to know which material has the best properties.
- The purpose is just to provide a general guideline for category selection.

Type	Advantages	Disadvantages
Low-Fidelity Prototype	• Lower development cost • Evaluate multiple design concepts • Useful communication device • Address screen layout issues • Useful for identifying market requirements • Proof-of-concept	• Limited error checking • Poor detailed specification to code to • Facilitator-driven • Limited utility after requirements established • Limited usefulness for usability tests • Navigational and flow limitations
High-Fidelity Prototype	• Complete functionality • Fully interactive • User-driven • Clearly defines navigational scheme • Use for exploration and tests • Look and feel of final product • Serves as a living specification • Marketing and sales tool	• More expensive to develop • Time-consuming to create • Inefficient for proof-of-concept designs • Not effective for requirements gathering

The purpose is just to provide a general guideline for category selection. For example

- Graphite epoxy has the highest tensile strength
- Graphite epoxy has the highest yield strength
- Polycarbonate has the highest percentage of elongation
- Alumina ceramic has the highest modulus of elasticity
- Polycarbonate has the highest coefficient of thermal expansion
- 01 Tool steel has the highest melting temperature
- C268 copper has the highest thermal conductivity
- C268 copper has the highest density
- 7075 aluminum has the most efficient cost per pound
- 01 Tool steel has the most efficient cost per unit volume
- 4340 Steel has the highest hardness value

Material Selection for Hi-Fi Prototypes

- When selecting a material, there are many areas of design concern. One needs to define the objective, such as what is to be maximized or minimized?
- Does it need to be made cheap, lightweight, increase safety, etc., or a combination of these things?
- One needs to consider the function of the material, such as what does the component do?
- Will it support a load, contain a pressure, transmit heat, etc.?

It may be necessary to consider the following application issues in selecting materials:

- ❑ Force and load magnitude
- ❑ Creep
- ❑ Fatigue
- ❑ Deformation
- ❑ In-service temperature
- ❑ Exposure to UV light (sunlight)
- ❑ Exposure to moisture
- ❑ Weather, etc.

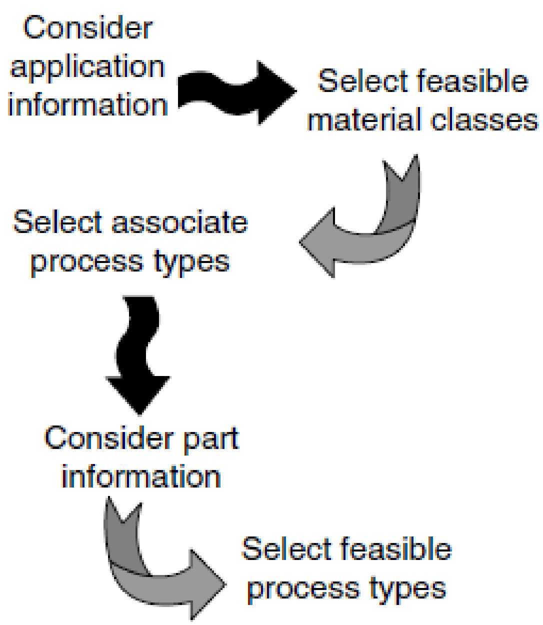
Physical properties	• Density, viscosity, porosity, permeability, reflectivity, crystal structure, etc.
Mechanical characteristics	• Strength (ultimate strength, yield strength, shear strength)
	• Stress–strain curve
	• Ductility
	• Modulus of elasticity (tension and compression)
	• Poisson's ratio
	• Hardness
Fatigue characteristics	• Corrosion fatigue
	• High load/low load/extended life
	• Constant amplitude load
	• Spectrum load
	• Fatigue strength
	• Sample smoothness, notched, etc.
Fracture characteristics	• Fracture toughness
	• Flaw growth
	• Crack instability

Thermal properties	• Coefficient of thermal expansion • Emissivity • Absorptivity • Melting/boiling points • Heat transfer coefficient • Specific heat • Thermal conductivity • Thermal shock resistance
Manufacturing	• Producibility • Availability • Processing characteristics (machinability, castability, weldability, moldability, heat treatability, formability and forgeability, hardenability) • Minimum handling thickness • Joining techniques • Quality assurance

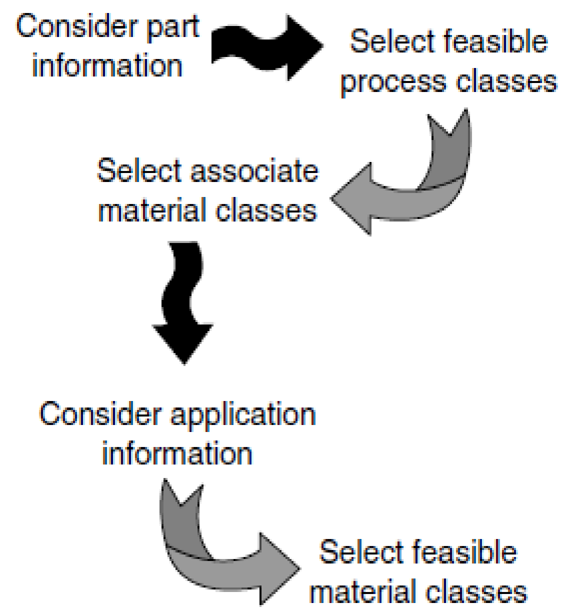
Hostile environments	• Moisture • Temperature • Acidity/alkalinity • Salt solution • Ammonia • Hydrogen attack • Nuclear hardness, nuclear half-life
Others	• Electrical, chemical, corrosion, optical properties • Repairability • Reliability

Material Selection for Hi-Fi Prototypes

- There are two approaches for material selection. One is “material-first,” based on choosing the material first and then selecting feasible processes.
- The other is “process-first” based on choosing the process first and then selecting feasible materials.



Material selection procedure: material-first.



Material selection procedure: process-first.

Modeling of Material Properties

- The purpose of this topic is to use examples *to illustrate the benefits of modeling material properties* to help in product design.
- Modeling is necessary to achieve required system behavior.

1. Aesthetic Modeling

- One interesting property of a material is its softness. Some products will need to be touched and thus should be designed to be soft.

  Examples: Sponge, cloths, blankets, etc.

- How would one specify a soft material? Material softness, S, can be defined as:

$$S = EH$$

Where, H is the hardness: resistance to indentation and scratching, E is the modulus of elasticity

- If S is small, the material feels soft.

Modeling of Material Properties

2. Warmth Modeling

- Sometimes one would like a product to feel warm and thus the material should be chosen so that it can let the users feel warm.
- A material feels "cold" to the touch if it conducts heat away from the finger quickly, and feels warm if it resists heat away from the finger.
- Assume that heat flows from the finger into a surface such that after time 't' a depth 'x' of material has been warmed significantly:

$$x = a \times t^{0.5}$$

and thermal diffusivity of the material,

$$a = K/(p \times C_p)$$

Where, K, p and C_p are thermal conductivity, material density and specific heat.

The quantity of heat that has left the area of the finger in time t is

$$Q = x \times p \times C_p$$

Modeling of Material Properties

3. Abrasion-resistant Modeling

- Abrasion resistance is the ability of a material to withstand mechanical actions such as rubbing and scraping.
- Abrasion resistance is basically determined by the material hardness, H.
- When one material can scratch another material, this material is more abrasion resistant than the other.

4. Pitch Modeling

- How would one select a material for a product that requires special sound characteristics?
- Sound frequency, or pitch, can be heard when an object is struck. Pitch P is related to the modulus of elasticity E and density *p*:

$$\mathrm{P} = (\mathrm{E}/p)^{0.5}$$

- If P is small, the material's pitch is low. If P increases, the material's pitch becomes higher.

Modeling of Material Properties

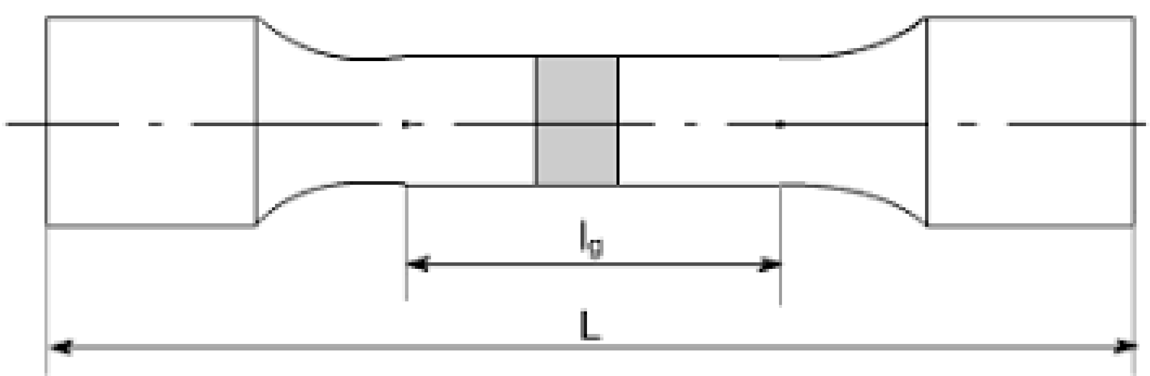
5. Sound Absorption Modeling

- The proportion of sound absorbed by a surface is called the sound absorption coefficient.
- Material of 0.8 in coefficient will absorb 80% of the sound that hits it, reflecting 20%.
- It is sometimes important to select a material which can absorb noise in the environment.
- It has been studied that a sound level of above 50dB can impair concentration, and a continued sound level above 90dB can cause damage to hearing.
- *For example*, to design a quiet car on the highway, it may be necessary to determine how loud the outside noise will be in the car when driving on the highway with windows and doors closed.
- In order to feel comfortable, the interior noise should be below 30dB.

Modeling of Material Properties

6. Ductility Modeling

- Ductility is more commonly defined as the ability of a material to deform easily upon the application of a tensile force
- The percent elongation reported in a tensile test is defined as the maximum elongation of the gauge length divided by the original gauge length.



Modeling and Design of Materials & Structures

This section will help answer the following questions:

- Is there a way to break the material selection problem down to the basic equations?
- Is there a systematic easy procedure that can assist engineers in determining material selection?
- Is there a set method that considers both material properties and cost when creating a prototype?

Material selection, cost and structure design often are among the first things to consider in a design. For example, how would one go about prototyping a new bicycle frame?

Well, it is possible that it is required to choose a material that is stiff, lightweight, and inexpensive. To do this, it is necessary to find information about Young's modulus, density, strength, and the cost for many different materials. It is unlikely that the cheapest material will also be the lightest and stiffest, ***thus it may be necessary to make some efforts on formulating the respondent design.***

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This section summarizes a method that demonstrates how to break the structure–material coupling problem down into basic equations. Instead of doing a full structural analysis on a part during the material selection phase, this is much easier.

- As shown in Figure, it is required to design a cylindrical tie-rod to carry a tensile force F without failure. To develop equations for material selection, the total mass of the rod can be calculated as:

Modeling and Design of Materials & Structures

m = A * L* *p*

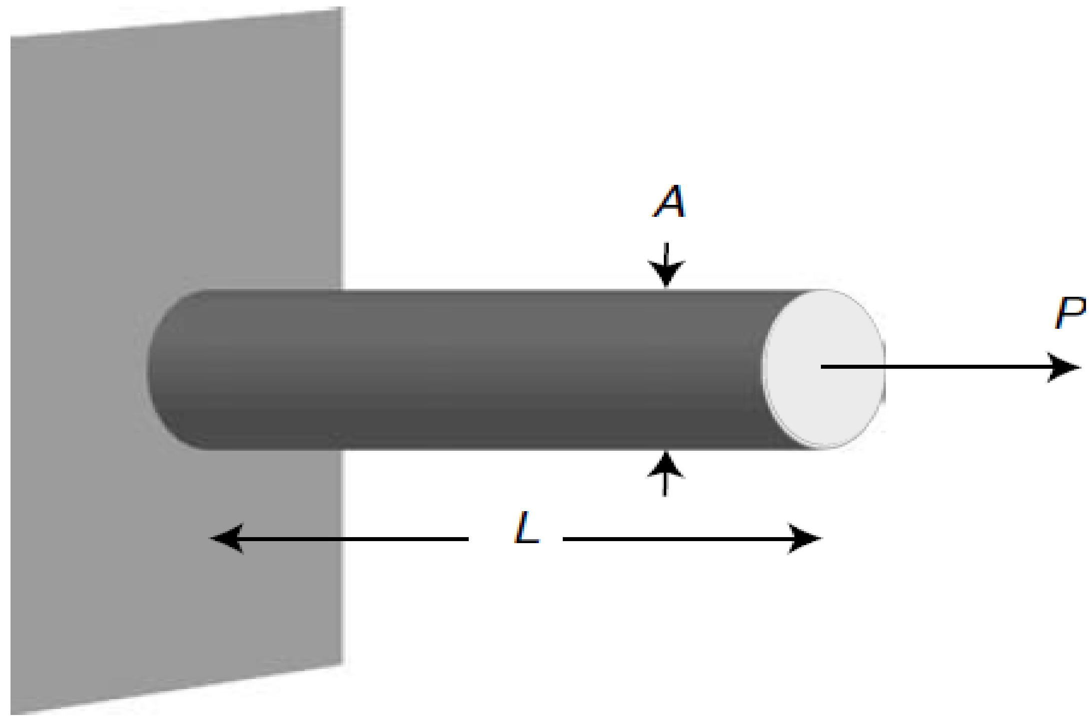
And, A = m/(L**p*)

The stress inside the rod should be less than the failure strength, or

F/A < Failure stress (K)

F . L . *p*/m < K

or F . L . *p*/K < m



Material	Cross section	Diameter	Weight	Density
A	A_A	D_A	W_A	ρ_A
B	A_B	D_B	W_B	ρ_B

Modeling and Design of Materials & Structures

The previous example illustrates a procedure to derive a structure problem into an index for material selection. The idea is to use the same structure, under the same load, but select from different materials for the associated structural cross-sectional areas.

One approach is called the **cost of unit strength**. For different materials, the associated cross-sectional area will change, the total weight of the structure will change, and thus the total cost of the material will change.