Material Selection

Chapter 10

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10.1 Introduction

- The goal of manufacturing is to create products and components that perform properly
- Due to advances in materials science, there is a wide array of available materials
  - The increase in the number of choices has often led to improper or poor materials selection
  - Sometimes, a more expensive alloy is chosen when a cheaper alloy would have been sufficient
- Design engineers have the responsibility of proper materials selection

Introduction

- Material selection processes should be constantly reevaluated
- Materials selection concerns are always changing
  - Environmental pollution
  - Recycling
  - Energy
  - Health or safety constraints
  - Geopolitical issues

Introduction

- Materials in many products have changed over the years

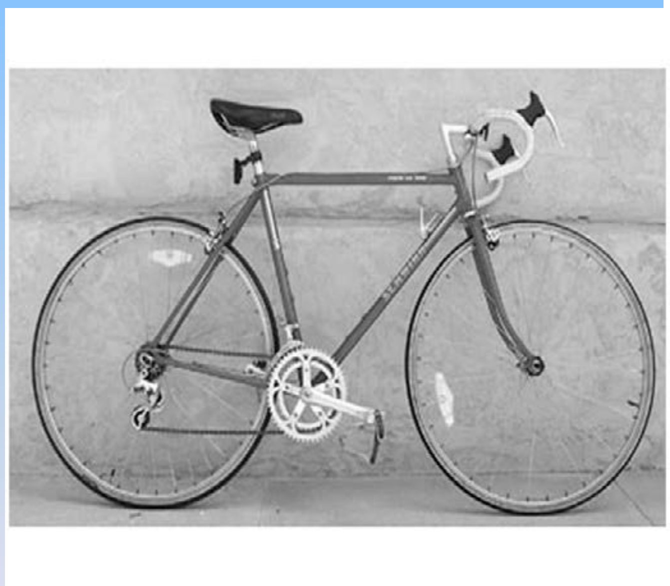

Figure 9-2 a) (Left) A traditional two-wheel bicycle frame (1970s vintage) made from joined segments of metal tubing,

b) (Right) a top-of-the-line (Tour de France or triathlon-type) bicycle with one-piece frame, made from fiber-reinforced polymer-matrix composite. (Courtesy of Trek Bicycle Corporation, Waterloo, WI.)

10.2 Material Selection and Manufacturing Processes

- Material and manufacturing processes are extremely interdependent
- Change in a material will likely cause a change in the manufacturing process needed
- A successful product has gone through both proper material selection and processing selection

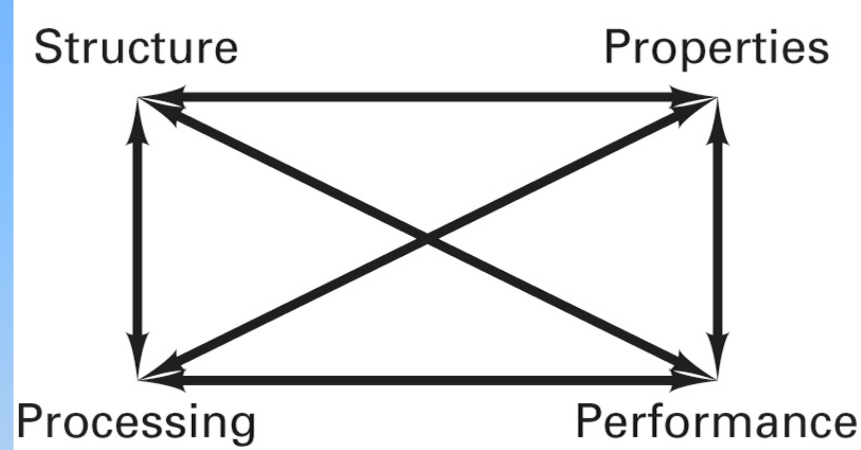

Figure 9-4 Schematic showing the interrelation among material, properties, processing, and performance.

Example of Material Changes in a Vacuum

TABLE 9-1 Examples of Material Selection and Substitution in the Redesign of a Vacuum Cleaner

Part	Former Material	New Material	Benefits
Bottom plate	Assembly of steel stampings	One-piece aluminum die casting	More convenient servicing
Wheels (carrier and caster)	Molded phenolic	Molded medium-density polyethylene	Reduced noise
Wheel mounting	Screw-machine parts	Preassembled with a cold-headed steel shaft	Simplified replacement, more economical
Agitator brush	Horsehair bristles in a die-cast zinc or aluminum brush back	Nylon bristles stapled to a polyethylene brush back	Nylon bristles last seven times longer and are now cheaper than horsehair
Switch toggle	Bakelite molding	Molded ABS	Breakage eliminated
Handle tube	AISI 1010 lock-seam tubing	Electric seam-welded tubing	Less expensive, better dimensional control
Handle bail	Steel stamping	Die-cast aluminum	Better appearance, allowed lower profile for cleaning under furniture
Motor hood	Molded cellulose acetate (replaced Bakelite)	Molded ABS	Reasonable cost, equal impact strength, much improved heat and moisture resistance: eliminated warpage problems
Extension-tube spring latch	Nickel-plated spring steel, extruded PVC cover	Molded acetal resin	More economical
Crevice tool	Wrapped fiber paper	Molded polyethylene	More flexibility
Rug nozzle	Molded ABS	High-impact styrene	Reduced costs
Hose	PVC-coated wire with a single-ply PVC extruded covering	PVC-coated wire with a two-ply PVC extruded covering separated by a nylon reinforcement	More durability, lower cost
Bellows, cleaning-tool nozzles, cord insulation, bumper strips	Rubber	PVC	More economical, better aging and color, less marking

Source: Metal Progress, by permission.

10.3 The Design Process

- Design is the first stage in manufacturing processes
  - What it is
  - What properties must it possess
  - What material
  - How to make it
  - How many to make
  - What conditions will it see during use

Steps for Design

- 1. Conceptual
  - Several concepts may be considered
- 2. Functional
  - Workable designs are developed
  - Detailed plan for manufacturing
  - Prototyping
- 3. Production
  - Full production
  - Production speeds and quantities

10.4 Procedures for Material Selection

- General sequence of product design
  - design→material selection→process selection→production→evaluation→redesign
- Case-history method
  - Evaluates what has been done in the past
- Modification of an existing product
  - Evaluates the current product and manufacturing techniques
  - Changes or improves upon features of the existing product
- Development of a new product
  - Follows the full sequence of product design above

Geometric Considerations

- Relative size
- Shape complexity
- Specified dimensions
- Precision
- Component interaction
- Surface-finishes
- Tolerances
  - Tolerances due to environmental or usage concerns
- Minor changes to improve manufacture or performance

Mechanical Properties

- Static strength
- Brittle fracture
- Plastic deformation
- Allowable bend, stretch, twist, or compress
- Impact loadings
- Vibrations or cyclic loadings
- Wear resistance
- Operating temperatures

Physical Properties (Electrical, Magnetic, Thermal, and Optical)

- Electrical requirements
  - Conductivity, resistivity
- Magnetic
- Thermal conductivity
- Thermal expansion
- Optical requirements
- Weight
- Appearance (color, texture, feel)

Environmental Considerations

- Operating temperatures
- Corrosion
- Erosion
- Lifetime
- Fatigue
- Expected level of maintenance
- Diassembly
- Repairability
- Recyclability

Manufacturing Concerns

- Quantity
- Rate
- Level of quality
- Quality control and inspection
- Assembly concerns
- Section thickness
- Standard sizes and shapes
- Liability if product failure occurs
- End-of-use disposal

Proper Materials Selection

- All factors and service conditions must be met
- Absolute requirements
  - No compromise possible
- Relative requirements
  - Compromises can be made
  - Good, better, best are all acceptable

10.5 Additional Factors to Consider

- Handbook data is valuable in determining materials
- Note the conditions under which values for materials were obtained
- Cost is often one of the biggest additional factors
  - Often, compromises between material properties and cost must be made
- Material availability
- Are there any possible misuses on the part of the consumer?
- Have there been failures for similar products?
- Material’s usage history
- Material standardization

10.6 Consideration of the Manufacturing Process

- Overall attractiveness
  - Physical properties
  - Mechanical properties
  - Formability
- Economical concerns
- All processes are not compatible with all materials

10.7 Ultimate Objective

- Develop a combination of material and processes that is the best solution
- Material or manufacturing selection normally imposes restrictions or limitations on the other
- Economics, environment, energy, efficiency, recycling, inspection, and serviceability are important deciding factors

Decision Models

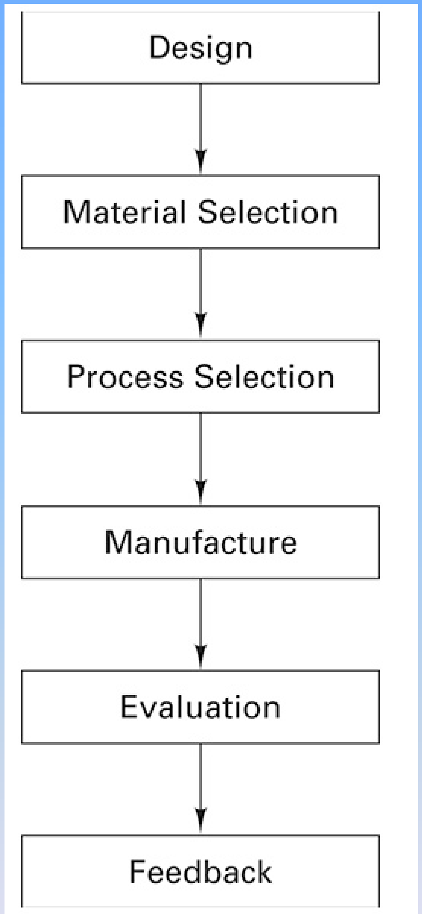

Figure 9-5 Sequential flow chart showing activities leading to the production of a part or product.

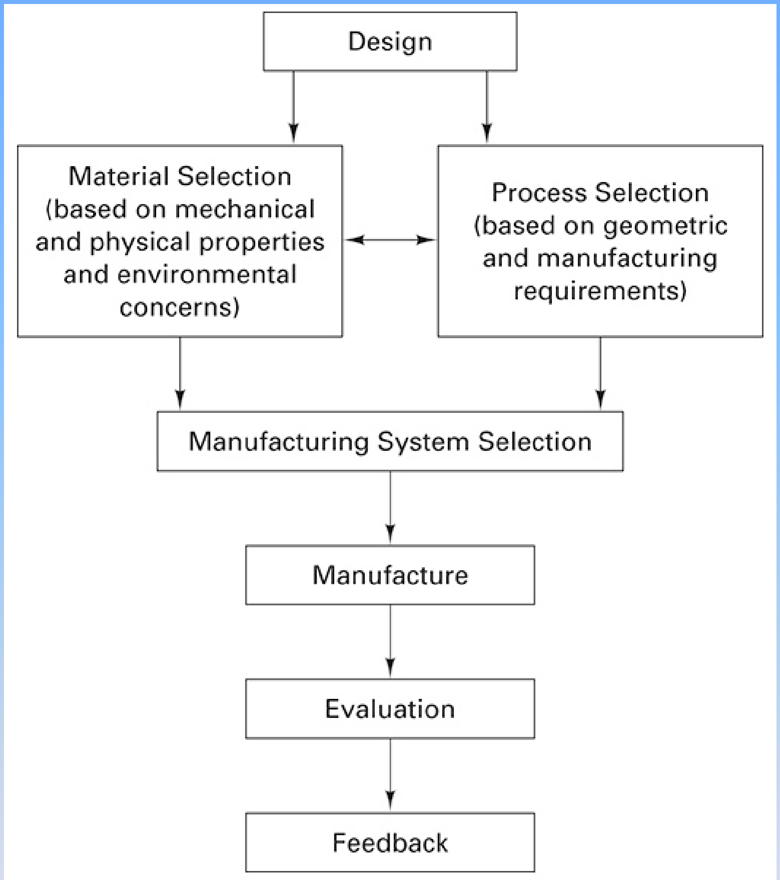

Figure 9-6 Alternative flow chart showing parallel selection of material and process.

Compatibility

Figure 9-7 Compatibility chart of materials and processes. Selection of a material may restrict possible processes. Selection of a process may restrict possible materials.

Process \ Material	Irons	Steel	Aluminum	Copper	Magnesium	Nickel	Refractory Metals	Titanium	Zinc
Sand Casting	X	X	X	X	X	X			0
Permanent Mold Cast	X	0	X	0	X	0			0
Die Casting			X	0	X				X
Investment Casting		X	X	X	0	0			
Closed-Die Forging		X	0	0	0	0	0	0	
Extrusion		0	X	X	X	0	0	0	
Cold Heading		X	X	X		0			
Stamping, Deep Draw		X	X	X	0	X		0	0
Screw Machine	0	X	X	X	0	X	0	0	0
Powder Metallurgy	X	X	0	X		0	X	0	

Key: X = Routinely performed
0 = Performed with difficulty, caution, or some sacrifice (such as die life)
Blank = Not recommended

10.8 Materials Substitution

- Care should be taken so that all requirements are still met
- The total picture should be considered so that any possible compromises can be determined
  – Aluminum sheets have replaced steel for weight reduction, but vibration problems require special design considerations

Material Substitutions

TABLE 9-2 Material Substitutions to Reduce Weight in an Automobile[a]

New Material	Previous Material	Weight Reduction	New Relative Cost
High-strength steel	Mild steel	10%	100% (no change)
Aluminum	Steel or cast iron	40–60%	130–200%
Magnesium	Steel or cast iron	60–75%	150–250%
Magnesium	Aluminum	25–35%	100–150%
Glass fiber reinforced plastic	Steel	25–35%	100–150%

[a] Data taken from "Automotive Materials in the 21st Century," by William F. Powers, published in *Advanced Materials and Processes*, May 2000.

Material Substitutions

- Causes of product failure
  - Failure to know and use the best materials information
  - Failure to account for all reasonable material uses
  - Use of materials with insufficient data
  - Inadequate quality control
  - Material selection made by unqualified people

10.10 Aids to Material Selection

- There is an enormous amount of resources available for materials selection
- *Metals Handbook*, published by ASM International
- *ASM Metals Reference Book*
- Handbooks are available for specific classes of materials
- American Metal Market provides material costs
- *Materials Selection in Mechanical Design* by M. F. Ashby
- Computer software

Summary

- Proper materials selection is vital to a product’s success
- The design engineer is responsible for materials selection
- Materials and process selection go hand-in-hand
- Data should be used to validate materials selection