Chapter 9

MATERIAL SELECTION

9.1 INTRODUCTION

The objective of manufacturing operations is to make products or components that adequately perform their intended task. Meeting this objective implies the manufacture of components from selected engineering materials, with the required geometrical shape and precision and with companion material structures and properties that are optimized for the service environment. The ideal product is one that will just meet all requirements. Anything better will usually incur added cost through higher-grade materials, enhanced processing, or improved properties that may not be necessary. Anything worse will likely cause product failure, dissatisfied customers, and the possibility of unemployment.

It was not that long ago that each of the materials groups had its own well-defined uses and markets. Metals were specified when strength, toughness, and durability were the primary requirements. Ceramics were generally limited to low-value applications where heat or chemical resistance was required and any loadings were compressive. Glass was used for its optical transparency, and plastics were relegated to low-value applications where low cost and light weight were attractive features and performance properties were secondary.

Such clear delineations no longer exist. Many of the metal alloys in use today did not exist as little as 30 years ago, and the common alloys that have been in use for a century or mere have been much improved due to advances in metallurgy and production processes. New on the scene are amorphous metals, dispersion-strengthened alloys produced by powder metallurgy, mechanical alloyed products, and directionally solidified materials. Ceramics, polymers, and composites are now available with specific properties that often transcend the traditional limits and boundaries. Advanced structural materials offer higher strength and stiffness; strength at elevated temperature; light weight; and resistance to corrosion, creep, and fatigue. Other materials have enhanced thermal, electrical, optical, magnetic, and chemical properties.

To the inexperienced individual, "wood is wood," but to the carpenter or craftsman, oak is best for one application, while maple excels for another, and yellow pine is preferred for a third. The ninth edition of "Woldman's Engineering Alloys” includes over 56,000 metal alloys, and that doesn't consider polymers, ceramics, or composites. Even if we eliminate the obsolete and obscure, we are still left with tens of thousands of options from which to select the "right" or "best" material for the task at hand.

Unfortunately, the availability of so many alternatives has often led to poor materials selection. Money can be wasted in the unnecessary specification of an expensive alloy or one that is difficult to fabricate. At other times, these materials may be absolutely necessary, and selection of a cheaper alloy would mean certain failure. It is the responsibility of the design and manufacturing engineer, therefore, to be knowledgeable in the area of engineering materials and to be able to make the best selection among the numerous alternatives.

In addition, it is also important that the material selection process be one of constant reevaluation. New materials are continually being developed, others may no longer be available, and prices are always subject to change. Concerns regarding environmental pollution, recycling, and worker health and safety may impose new constraints. Desires for weight reduction, energy savings, or improved corrosion resistance may well motivate a change in engineering material. Pressures from domestic and foreign competition, increased demand for quality and serviceability, or negative customer feedback can all prompt a reevaluation. Finally, the proliferation of product liability actions, many of which are the result of improper material use, has further emphasized the need for constant reevaluation of the engineering materials in a product.

The automotive industry alone consumes approximately 60 million metric tons of engineering materials worldwide every year - primarily steel, cast iron, aluminum, copper, glass, lead, polymers, rubber, and zinc. In recent years, the drive toward lighter, more fuel-efficient vehicles has led to an increase in the use of the lightweight metals and high-strength steels, as well as plastics and composites.

A million metric tons of engineering materials go into aerospace applications every year. The principal materials tend to be aluminum, magnesium, titanium, superalloys, polymers, rubber, steel, metal-matrix composites, and polymer-matrix composites. Competition is intense, and materials substitutions are frequent. The use of advanced composite materials in aircraft construction has risen from less than 2% in 1970 to the point where they now account for one-quarter of the weight of the U.S. Air Force's Advanced Tactical Fighter and will soon appear in the main fuselage of commercial planes. Titanium is used extensively for applications that include the exterior skins surrounding the engines, as well as the engine frames. The cutaway section of the Rolls Royce jet engine in Figure 9-1a reveals the myriad of components - each with its own characteristic shape, precision, stresses, and operating temperatures—that require a variety of engineering materials. Figure9-lb shows an actual engine in a manner that reveals both its size and complexity. The intake fan diameter is nearly 3 meters in diameter (9 ft, 8 in.).

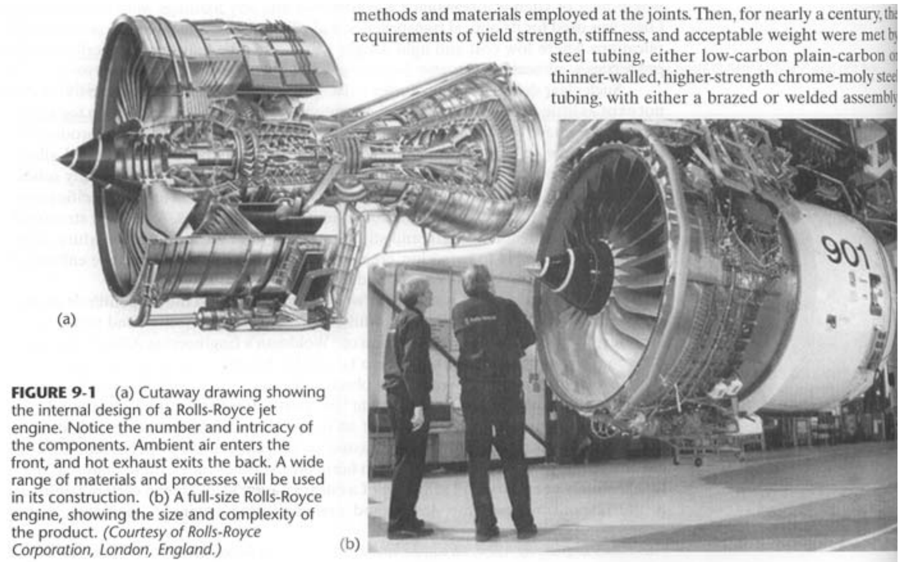

FIGURE 9-1 (a) Cutaway drawing showing the internal design of a Rolls-Royce jet engine. Notice the number and intricacy of the components. Ambient air enters the front, and hot exhaust exits the back. A wide range of materials and processes will be used in its construction. (b) A full-size Rolls-Royce engine, showing the size and complexity of the product. *(Courtesy of Rolls-Royce Corporation, London, England.)*

The earliest two-wheeled bicycle frames were constructed of wood, with various methods and materials employed at the joints. Then for nearly a century.the requirements of yield strength, stiffness, and acceptable weight were met by steel tubing, either low-carbon plain-carbon or thinner-walled, higher-strength chrome-moly steel tubing, with either a brazed or welded assembly.

In the 1970s a full circle occurred. Where a pair of bicycle builders (the Wright brothers) pioneered aerospace, the aerospace industry returned to revolutionize bicycles. Light-weight frames were constructed from the aerospace materials of high-strength aluminum, titanium, graphite-reinforced polymer, and even beryllium. Wall thickness and cross-section profiles were often modified to provide strength and rigidity. Materials paralleled function as bicycles specialized into road bikes, high-durability mountain bikes, and ultra-light racing bikes. Further building on the aerospace experience, the century-old tubular frame has recently been surpassed by one-piece monocoque frames of either die-cast magnesium or continually wound carbon-fiber epoxy tapes with or without selective metal reinforcemc nts. One top-of-the-line carbon-fiber frame now weighs only 2.5 pounds! Figure 9-2 compares a traditional tubular frame with one of the newer designs.

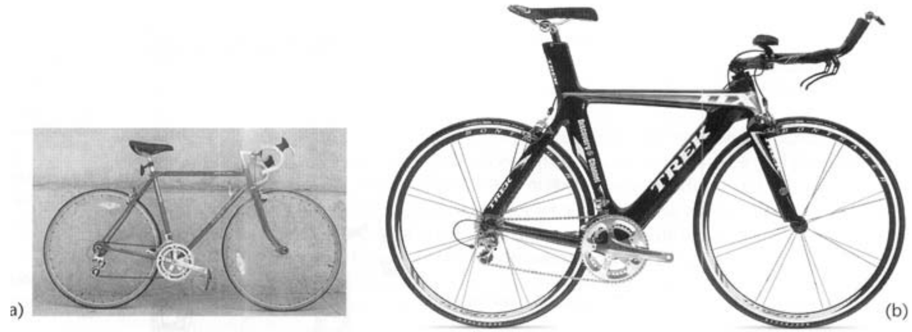

FIGURE 9-2 (a) A traditional two-wheel bicycle frame (1970s vintage) made from joined segments of metal tubing; (b) a top-of-the-line (Tour de France or triathlon-type) bicycle with one-piece frame, made from fiber-reinforced polymer–matrix composite. *(Courtesy of Trek Bicycle Corporation, Waterloo, WI.)*

Window frames were once made almost exclusively from wood. While wood remains a competitive material, a trip to any building supply will reveal a selection that includes anodized aluminum in a range of colors, as well as frames made from colored vinyl and other polymers. Each has its companion advantages and limitations. Auto bodies were fabricated from steel sheet and assembled by resistance spot welding. Designers now select from steel, aluminum, and polymeric sheet-molding compounds and may use adhesive bonding to produce the joints.

The vacuum cleaner assembly shown in Figure 9-3, while not a current model, is typical of many engineering products, where a variety of materials are used for the various components. Table 9-1 lists the material changes that were recommended in just one past revision of the appliance. The materials for 12 components were changed completely, and that for a thirteenth was modified. Eleven different reasons were given for the changes. An increased emphasis on lighter weight has brought about even further changes in both design and materials.

The list of available engineering materials now includes metals and alloys, ceramics, plastics, elastomers, glasses, concrete, composite materials, and others. It is not surprising, therefore, that a single person might have difficulty making the necessary decisions concerning the materials in even a simple manufactured product. More frequently, the design engineer or design team will work in conjunction with various materials specialists to select the materials that will be needed to convert today's designs into tomorrow's reality.

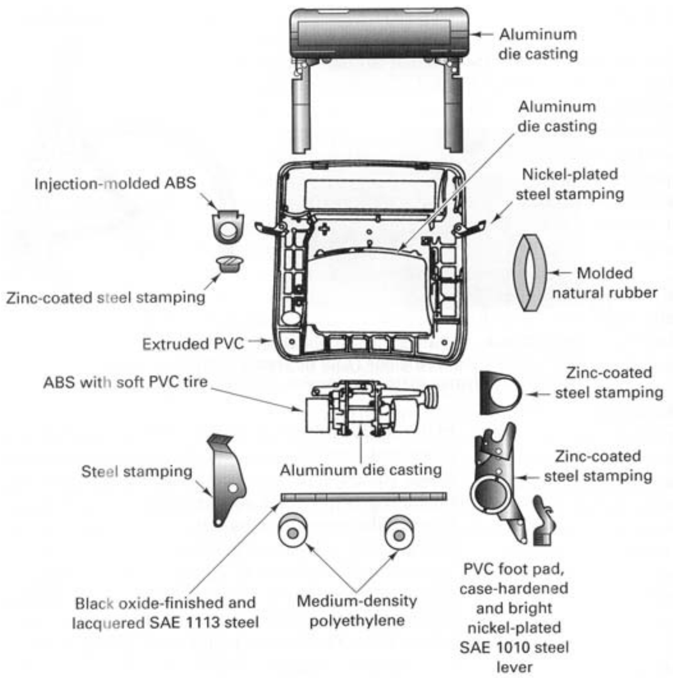

Figure 9.3 Materials used in various parts of a vacuum cleaner assembly

9.2 MATERIAL SELECTION AND MANUFACTURING PROCESSES

The interdependence between materials and their processing must also be recognized. New processes frequently accompany new materials, and their implementation can often cut production costs and improve product quality. A change in material may well require a change in the manufacturing process. Conversely, improvements in processes may enable a reevaluation of the materials being processed. Improper processing of a well-chosen material can definitely result in a defective product. If satisfactory products are to be made, considerable care must be exercised in selecting both the engineering materials and the manufacturing processes used to produce the product.

Most textbooks on materials and manufacturing processes spend considerable time discussing the interrelationships between the structure and properties of engineering materials, the processes used to produce a product, and the subsequent performance.

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.

As Figure 9-4 attempts to depict, each of these aspects is directly related to all of the others. An engineering material may possess different properties depending upon its structure. Processing of that material can alter the structure, which in turn will alter the properties. Altered properties certainly alter performance. The objective of manufacturing, therefore, is to devise an optimized system of material and processes to produce the desired product.

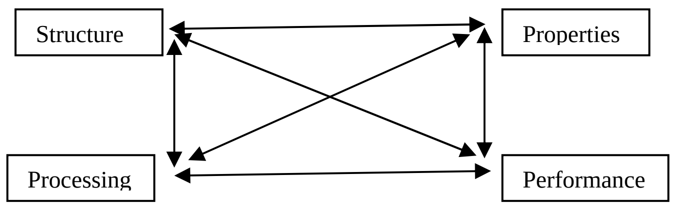

Figure 9-4 Schematic showing the interrelation among material, properties, processing and performance

9.3 THE DESIGN PROCESS

The first step in the manufacturing process is *design*—the determining in rather precise detail what it is that we want to produce and, for each component of the product or assembly, what properties it must possess, what to make it out of, how to make it, how many to make, and what conditions it will see during use.

Design usually takes place in several distinct stages: (1) conceptual, (2) functional, and (3) production. During the *conceptual-design* stage, the designer is concerned primarily with the functions that the product is to fulfill. Several concepts are often considered, and a determination is made that the concept is either not practical, or is sound and should be developed further. Here the only concern about materials is that materials exist that could provide the desired properties. If such materials are not available, consideration is given to whether there is a reasonable prospect that new ones could be developed within the limitations of cost and time.

At the *functional- or engineering-design stage*, a workable design is developed, including a detailed plan for manufacturing. Geometric features are determined and dimensions are specified, along with allowable tolerances. Specific materials are selected for each component. Consideration is given to appearance, cost, reliability, producibility, and serviceability, in addition to the various functional factors. It is important to have a complete understanding of the functions and performance requirements of each component and to perform a thorough materials analysis, selection, and specification. If these decisions are deferred, they may end up being made by individuals who are less knowledgeable about all of the functional aspects of the product.

Often, a *prototype* or working model is constructed to permit a full evaluation of the product. It is possible that the prototype evaluation will show that some changes have to be made in either the design or material before the product can be advanced to production. This should not be taken, however, as an excuse for not doing a thorough job. It is strongly recommended that all prototypes be built with the same materials that will be used in production and, where possible, with the same manufacturing techniques. It is of little value to have a perfectly functioning prototype that cannot be manufactured economically in the desired volume or one that is substantially different from what the production units will be like.

In the *production-design* stage, we look to full production and determine if the proposed solution is compatible with production speeds and quantities. Can the parts be processed economically, and will they be of the desired quality?

As actual manufacturing begins, changes in both the materials and processes may be suggested. In most cases, however, changes made after the tooling and machinery have been placed in production tend to be quite costly. Good up-front material selection and thorough product evaluation can do much to eliminate the need for change.

As production continues, the availability of new materials and new processes may well present possibilities for cost reduction or improved performance. Before adopting new materials, however, the candidates should be evaluated very carefully to ensure that all of their characteristics related to both processing and performance are well established. Remember that it is indeed rare that as much is known about the properties and reliability of a new material as an established one. Numerous product failures and product liability cases have resulted from new materials being substituted before their long-term properties were fully known.

9.4 PROCEDURES FOR MATERIAL SELECTION

The selection of an appropriate material and its subsequent conversion into a useful product with desired shape and properties can be a rather complex process. Nearly every engineered item goes through a sequence of activities that includes: design → material selection → process selection → production → evaluation → and possible redesign or modification. Numerous engineering decisions must be made along the way.

Several methods have been developed for approaching a design and selection problem. The *case-history method* is one of the simplest. Begin by evaluating what has been done in the past (engineering material and method of manufacture) or what a competitor is currently doing. This can yield important information that will serve as a starting base. Then, either duplicate or modify the details of that solution. The basic assumption of this approach is that similar requirements can be met with similar solutions.

The case-history approach is quite useful, and many manufacturers continually examine and evaluate their competitors' products for just this purpose. The real issue here, however, is "how similar is similar." A minor variation in service requirement, such as a different operating temperature or a new corrosive environment, may be sufficient to justify a totally different material and manufacturing method. In addition, this approach lends to preclude the use of new materials, new technology, and any manufacturing advances that may have occurred since the formulation of the original solution. It is equally unwise, however, to totally ignore the benefits and insights that can be gained through past experience.

Other design and selection activities occur during the *modification of an existing product*, generally in an effort to reduce cost, improve quality, or overcome a problem or defect that has been encountered. A customer may have requested a product like the current one but capable of operating at higher temperatures, or in an acidic environment, or at higher pressure. Efforts here generally begin with an evaluation of the current product and its present method of manufacture. The most frequent pitfall, however, is to overlook one of the original design requirements and recommend a change that in some way compromises the total performance of the product. Examples of such oversights, where materials have been changed to meet a specific objective, are provided in Section 9.8.

The safest and most comprehensive approach to part manufacture is to follow the full sequence of design, material selection, and process selection, considering all aspects and all alternatives. This is the approach one would take in the *development of an entirely new product.*

Before any decisions are made, take the time to fully define the needs of the product. What exactly is the "target" that we wish to hit? We must develop a clear picture of all of the characteristics necessary for this part to adequately perform its intended function and do so with no prior biases about material or method of fabrication. These requirements will fall into three major areas: (1) shape or geometry considerations, (2) property requirements, and (3) manufacturing concerns. By first formulating these requirements, we will be in a better position to evaluate candidate materials and companion methods of fabrication.

GEOMETRIC CONSIDERATIONS

A dimensioned sketch can answer many of the questions about the size, shape, and complexity of a part, and these *geometric or shape considerations* will have a strong influence on decisions relating to the proposed method or methods of fabrication. While many features of part geometry are somewhat obvious, geometric considerations are often more complex than first imagined. Typical questions might include:

1. What is the relative size of the component?
2. How complex is its shape? Are there any axes or planes of symmetry? Are there any uniform cross sections? Could the component be divided into several simpler shapes that might be easier to manufacture?
3. How many dimensions must be specified?
4. How precise must these dimensions be? Are all precise? How many are restrictive, and which ones?
5. How does this component interact geometrically with other components? Are there any restrictions imposed by the interaction?
6. What are the surface-finish requirements? Must all surfaces be finished? Which ones do not?
7. How much can each dimension change by wear or corrosion and the part still function adequately?
8. Could a minor change in part geometry increase the ease of manufacture or improve the performance (fracture resistance, fatigue resistance, etc.) of the part?

Producing the right shape is only part of the desired objective. If the part is to perform adequately, it must also possess the necessary *mechanical and physical properties*, as well as the ability to endure anticipated environments for a specified period of time. *Environmental considerations* should include all aspects of shipping, storage, and use! Some key questions include those listed in the following three sections.

MECHANICAL PROPERTIES

1. How much static strength is required?
2. If the part is accidentally overloaded, is it permissible to have a sudden brittle fracture, or is plastic deformation and distortion a desirable precursor to failure?
3. How much can the material bend, stretch, twist, or compress under load and still function properly?
4. Are any impact loadings anticipated? If so, of what type, magnitude, and velocity?
5. Can you envision vibrations or cyclic loadings? If so, of what type, magnitude, and frequency?
6. Is wear resistance desired? Where? How much? How deep?
7. Will all of the above requirements be needed over the entire range of operating temperature? If not, which properties are needed at the lowest extreme? At the highest extreme?

PHYSICAL PROPERTIES (ELECTRICAL, MAGNETIC, THERMAL, AND OPTICAL)

1. Are there any electrical requirements? Conductivity? Resistivity?
2. Are any magnetic properties desired?
3. Are thermal properties significant? Thermal conductivity? Changes in dimension with change in temperature?
4. Are there any optical requirements?
5. Is weight a significant factor?
6. How important is appearance? Is there a preferred color, texture, or feel?

ENVIRONMENTAL CONSIDERATIONS

1. What are the lowest, highest, and normal temperatures the product will see? Will temperature changes be cyclic? How fast will temperature changes occur?
2. What is the most severe environment that is anticipated as far as corrosion or deterioration of material properties is concerned?
3. What is the desired service lifetime for the product?
4. What is the anticipated level of inspection and maintenance during use?
5. Should the product be manufactured with disassembly, repairability, or recyclability in mind?

MANUFACTURING CONCERNS

A final area of consideration is the variety of factors that will directly influence the method of manufacture. Some of these manufacturing concerns are:

1. How many of the components are to be produced? At what rate? (Note: One-of-a-kind parts and small quantities are rarely made by processes that require dedicated patterns, molds, or dies, since the expense of the tooling is hard to justify. High-volume, high-rate products may require automatable processes.)
2. What is the desired level of quality compared to similar products on the market?
3. What are the quality control and inspection requirements?
4. Are there any assembly (or disassembly) concerns? Any key relationships or restrictions with respect to mating parts?
5. What al e the largest and smallest section thicknesses?
6. Have standard sizes and shapes been specified wherever possible (both as finished shapes and as starting raw material)? What would be the preferred form of starting material (plate, sheet, foil, bar, rod, wire, powder, ingot)?
7. Has the design addressed the requirements that will facilitate ease of manufacture (machinability, castability, formability, weldability, hardenability)?
8. What is the potential liability if the product should fail?
9. Are there any end-of-use disposal concerns?

The considerations just mentioned are only a sample of the many questions that must be addressed when precisely defining what it is that we want to produce. While there is a natural tendency to want to jump to an answer, in this case a material and method of manufacture, time spent determining the various requirements will be well rewarded. Collectively, the requirements direct and restrict material and process selections. It is possible that several families of materials, and numerous members within those families, all appear to be adequate. In this case, selections may become a matter of preference. It is also possible, however, that one or more of the requirements will emerge as i dominant restrictor (such as the need for ultra-high strength, superior wear resistance, the ability to function at extreme operating temperatures, or the ability to withstand highly corrosive environments), and selection then becomes focused on those materials offering that specific characteristic.

It is important that *all* factors be listed and *all* service conditions and uses be considered. Many failures and product liability claims have resulted from engineering oversights or failure to consider the entire spectrum of conditions that a product might experience in its lifetime. Consider the failure of several large electric power transformers where fatigue cracks formed at the base of horizontal cooling fins that had been welded to the exterior of the casing. The subsequent loss of cooling oil through the cracks led to overheating and failure of the transformer coils. Since transformers operate under static conditions, fatigue was not considered in the original design and material selection. However, when the horizontal fins were left unsupported during shipping, the resulting vibrations were sufficient to induce the fatal cracks. It is also not uncommon for the most severe corrosion environment to be experienced during shipping or storage as opposed to normal operation. Products can also encounter unusual service conditions. Consider the numerous parts that failed on earthmoving and construction equipment when it was used in the construction of the trans-Alaskan oil pipeline. When this equipment was originally designed and the materials were selected, extreme subzero temperatures were not included as possible operating conditions.

Once we complete a thorough evaluation of the required properties, it may be helpful to assign a relative importance to the various needs. Some requirements may be absolutes, while others may be *relative*. Absolute requirements are those for which there can be no compromise. The consequence of not meeting them will be certain failure of the product. Materials that fall short of absolute requirements should be autotatically eliminated. For example, if a component must possess good electrical conductivity, most plastics and ceramics would not be appropriate. Relative or compromisable properties are those that frequently differentiate "good," "better," and "best," where all would be considered as acceptable.

9.5 ADDITIONAL FACTORS TO CONSIDER

When evaluating candidate materials, an individual is often directed to handbook-type data that has been obtained through standardized materials characterization tests. It is important to note the conditions of these tests in comparison with those of the proposed application. Significant variations in factors such as temperature, rates of loading, or surface finish can lead to major changes in a material's behavior. In addition, one should keep in mind that the handbook values often represent an average or mean and that actual material properties may vary to either side of that value. Where vital information is missing or the data may not be applicable to the proposed use, one is advised to consult with the various materials producers or qualified materials engineers.

At this point it is probably appropriate to introduce cost as an additional factor. Because of competition and marketing pressures, economic considerations are often as important as technical ones. However, we have chosen to adopt the philosophy that cost should not be considered until a material has been shown to meet the necessary requirements. If acceptable candidates can be identified, cost will certainly become an important part of the selection process, and both material cost and the cost of fabrication should be considered. Often, the final decision involves some form of compromise among material cost, ease of fabrication, and performance or quality. Numerous questions might be asked, such as:

1. Is the material too expensive to meet the marketing objectives?
2. Is a more expensive material justifiable if it offers improved performance?
3. How much additional expense might be justified to gain ease of fabrication?

In addition, it is important that the appropriate cost figures be considered. Material costs are most often reported in the form of dollars per pound or some other form of cost per unit weight. If the product has a fixed size, however, material comparisons should probably be based on cost per unit volume. For example, aluminum has a density about one-third that of steel. For products where the size is fixed, 1 pound of aluminum can be used to produce three times as many parts as 1 pound of steel. If the per-pound cost of aluminum were less than three times that of steel, aluminum would actually be the cheaper material. Whenever the densities of materials are quite different, as with magnesium and stainless steel, the relative rankings based on cost per pound and cost per cubic inch can be radically different.

Material availability is another important consideration. The material selected may not be available in the size, quantity, or shape desired, or it may not be available in any form at all. The diversity and reliability of supply may be additional factors that will facilitate competitive pricing and avoid production bottlenecks. If availability or supply may be a problem, one should be prepared to recommend alternative materials, provided that they, too, are feasible candidates for the specific use.

Still other factors to be considered when making material selections include:

1. Are there possible misuses of the product that should be considered? If the product is to be used by the general public, one should definitely anticipate the worst. Screw-drivers are routinely used as chisels and pry bars (different forms of loading from the intended torsional twist). Scissors may be used as wire cutters. Other products are similarly misused.
2. Have there been any failures of this or similar products? If so, what were the identified causes and have they been addressed in the current product? Failure analysis results should definitely be made available to the designers, who can directly benefit from them.
3. Has the material (or class of materials) being considered established a favorable or unfavorable performance record? Under what conditions was unfavorable performance noted?
4. Has an attempt been made to benefit from material standardization, whereby multiple components are manufactured from the same material or by the same manufacturing process? Although function, reliability, and appearance should not be sacrificed, one should not overlook the potential for savings and simplification that standardization has to offer.

9.6 CONSIDERATION OF THE MANUFACTURING PROCESS

The overall attractiveness of an engineering material depends not only on its physical and mechanical properties but also on our ability to shape it into useful objects in an economical and timely manner. Without the necessary shape, parts cannot perform, and without economical production, the material will be limited to a few high-value applications. For this reason, our material selection should be further refined by considering the possible fabrication processes and the suitability of each "prescreened" material to each of those processes. Familiarity with the various manufacturing alternatives is a necessity, together with a knowledge of the associated limitations, economics, product quality, surface finish, precision, and so on. All processes are not compatible with all materials. Steel, for example, cannot be fabricated by die casting. Titanium can be forged successfully by isothermal techniques but generally not by conventional drop hammers. Wrought alloys cannot be cast, and casting alloys are not attractive for forming.

Certain fabrication processes have distinct ranges of product size, shape, and thickness, and these should be compared with the requirements of the product. Each process has its characteristic precision and surface finish. Since secondary operations, such as machining, grinding, and polishing, all require the handling, positioning, and processing of individual parts, as well as additional tooling, they can add significantly to manufacturing cost. Usually it is best to hit the target with as few operations as possible. Some processes require prior heating or subsequent heat treatment. Still other considerations include production rate, production volume, desired level of automation, and the amount of labor required, especially if it is skilled labor. All of these concerns will be reflected in the cost of fabrication. There may also be additional constraints, such as the need to design a product so that it can be produced with existing equipment or facilities, or with a minimum of lead time, or with a minimal expenditure for dedicated tooling.

It is not uncommon for a certain process to be implied by the geometric details of a component design, such as the presence of cored features in a casting, the magnitude of draft allowances, or the recommended surface finish. The designer often specifies these features prior to consultation with manufacturing experts. It is best, therefore, to consider all possible methods of manufacture and, where appropriate, work with the designer to incorporate changes that would enable a more attractive means of production.

9.7 ULTIMATE OBJECTIVE

The real objective of this activity is to develop a manufacturing system - a combination of material and process (or sequence of processes) that is the best solution for a given product. Figure 9-5 depicts a series of activities that move from a well-defined set of needs and objectives through material and process selection to the manufacture and evaluation of a product. Numerous decisions are required, most of which are judgmental in nature. For example, we may have to select among "good," "better," and "best," where "better" and "best" carry increments of added cost, or make compromises when all of the requirements cannot be simultaneously met.

While Figure 9-5 depicts the various activities as having a definite, sequential pattern, one should be aware that they are often rearranged and are definitely interrelated. Figure 9-6 shows a modified form, where material selection and process selection have been moved to be parallel instead of sequential. It is not uncommon for one of the two selections to be dominant and the other to become dependent or secondary. For example, the production of a large quantity of small, intricate parts with thin walls, precise dimensions, and smooth surfaces is an ideal candidate for die casting. Material selection, therefore, may be limited to die-castable materials—assuming feasible alternatives are available. In a converse example, highly restrictive material properties, such as the ability to endure extremely elevated temperatures or severe corrosive environments, may significantly limit the material options. Fabrication options will tend to be limited to those processes that are compatible with the candidate materials.

In both models, decisions in one area generally impose restrictions or limitations in another. As shown in Fig 9-7 selection of a material may limit processes, and selection of a process may limit material. Each material has its own set of performance characteristics, both strengths and limitations. The various fabrication methods impart characteristic properties to the material, and all of these may not be beneficial (consider anisotropy, porosity, or residual stresses). Processes designed to improve certain properties (such as heat treatment) may adversely affect others. Economics, environment, energy, efficiency, recycling, inspection, and serviceability all tend to influence decisions.

On rare occasions, a single solution will emerge as the obvious choice. More likely, several combinations of materials and processes will all meet the specific requirements, each with its own strengths and limitations. Compromise, opinion, and judgment all enter into the final decision making, where our desire is to achieve the best solution while not overlooking a major requirement. Listing and ranking the required properties will help ensure that all of the necessary factors were considered and weighed in making the ultimate decision. If no material–process combination meets the requirements, or if the compromises appear to be too severe, it may be necessary to redesign the product, adjust the requirements, or develop new materials or processes.

The individuals making materials and manufacturing decisions must understand the product, the materials, the manufacturing processes, and all of the various interrelations. This often requires multiple perspectives and diverse expertise, and it is not uncommon to find the involvement of an entire team. Design engineers ensure that each of the requirements is met and that any compromise or adjustment in those requirements is acceptable. Materials specialists bring expertise in candidate materials and the effects of various processing. Manufacturing personnel know the capabilities of processes, the equipment available, and the cost of associated tooling. Quality and environmental specialists add their perspective and expertise. Failure analysis personnel can share valuable experience gained from past unsuccessful efforts. Customer representatives or marketing specialists may also be consulted for their opinions. Clear and open communication is vital to the making of sound decisions and compromises.

The design and manufacture of a successful product is an iterative, evolving, and continual process. The failure of a component or product may have revealed deficiencies in design, poor material selection, material defects, manufacturing defects, improper assembly, or improper or unexpected product use. The costs of both material and processing continually change, and these changes may prompt a reevaluation. The availability of new materials, technological advances in processing methods, increased restrictions in environment or energy, or the demand for enhanced performance of existing product all provide a continuing challenge. Materials availability may also have become an issue. A change in material may well require companion changes in the manufacturing process. Improvements in processing may warrant a reevaluation of the material.

Reference

Chpter 9 : DeGarmo et al, " Materials & Processes in Manufacturing", 10th Edition, Wiley, 2008.,