## INTRODUCTION

### 1.1 Definition of Manufacturing

As a field of study in the modern context, manufacturing can be defined two ways, one in term of technology and the other economic. ***Technologically***, Manufacturing is the application of physical and chemical processes to alter the geometry, properties, and/or appearance of a given starting material to make parts or products. Manufacturing also includes assembly of multiple parts to make products. The processes to accomplish manufacturing involve a combination of machinery, tools, power, and labor, as depicted in Figure 1.1(a).

***Economically***, Manufacturing is the transformation of materials into items of greater value by means of one or more processing and/or assembly operations, as depicted in Figure 1.1(b). The key point is that manufacturing adds value to the material by changing its shape or properties, or by combining it with other materials that have been similarly altered.

The material has been made more valuable through the manufacturing operations performed on it. When iron ore is converted into steel, value is added. When sand is transformed into glass, value is added. When petroleum is refined into plastic, value is added. And when plastic is molded into the complex geometry of a patio chair, it is made even more valuable.

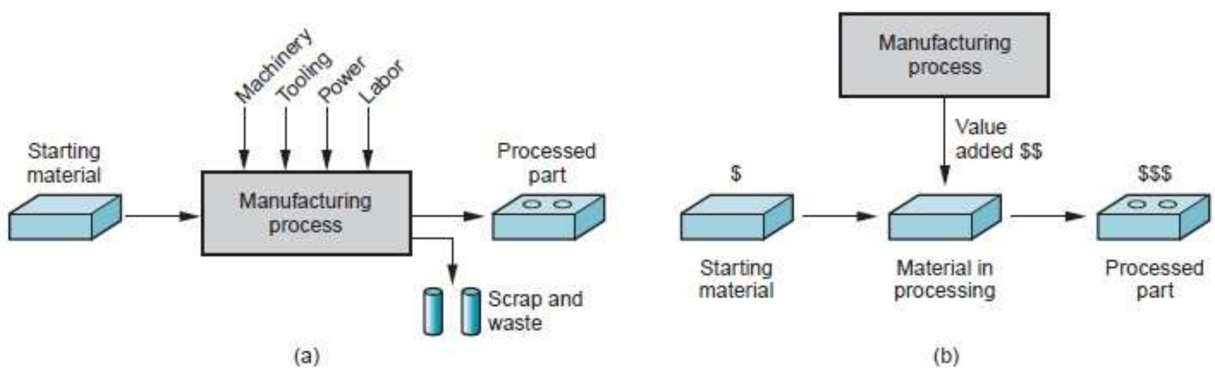


FIGURE 1.1: Two ways to define manufacturing: (a) as a technical process, and (b) as an economic process

The words Manufacturing and Production are often used interchangeably. The author's view is that production has a broader meaning than manufacturing. To illustrate, one might speak of ''crude oil production,'' but the phrase ''crude oil manufacturing'' seems out of place. Yet when used in the context of products such as metal parts or automobiles, either word seems okay.

### 1.2 Manufacturing Capability

A manufacturing plant consists of a set of processes and systems (and people, of course) designed to transform a certain limited range of materials into products of increased value. These three building blocks—materials, processes, and systems—constitute the subject of modern manufacturing. There is a strong interdependence among these factors. A company engaged in manufacturing cannot do everything. It must do only certain things, and it must do those things well. Manufacturing capability refers to the technical and physical limitations of a manufacturing firm and each of its plants. Several dimensions of this capability can be identified:

1. Technological processing capability,
2. Physical size and weight of product, and
3. Production capacity.

**Technological Processing Capability:** The technological processing capability of a plant (or company) is its available set of manufacturing processes. Certain plants perform machining operations, others roll steel billets into sheet stock, and others build automobiles.

A machine shop cannot roll steel, and a rolling mill cannot build cars. The underlying feature that distinguishes these plants is the processes they can perform. Technological processing capability is closely related to material type. Certain manufacturing processes are suited to certain materials, whereas other processes are suited to other materials. By specializing in a certain process or group of processes, the plant is simultaneously specializing in certain material types. Technological processing capability includes not only the physical processes, but also the expertise possessed by plant personnel in these processing technologies. Companies must concentrate on the design and manufacture of products that are compatible with their technological processing capability.

**Physical Product Limitations:** Another aspect of manufacturing capability is imposed by the physical product. A plant with a given set of processes is limited in terms of the size and weight of the products that can be accommodated. Large, heavy products are difficult to move. To move these products about, the plant must be equipped with cranes of the required load capacity. Smaller parts and products made in large quantities can be moved by conveyor or other means. The limitation on product size and weight extends to the physical capacity of the manufacturing equipment as well. Production machines come in different sizes. Larger machines must be used to process larger parts. The production and material handling equipment must be planned for products that lie within a certain size and weight range.

**Production Capacity:** A limitation on a plant's manufacturing capability is the production quantity that can be produced in a given time period (e.g., month or year). This quantity limitation is commonly called plant capacity, or production capacity, defined as the maximum rate of production that a plant can achieve under assumed operating conditions. The operating conditions refer to number of shifts per week, hours per shift, direct labor manning levels in the plant, and so on. These factors represent inputs to the manufacturing plant. Given these inputs, how much output can the factory produce?

Plant capacity is usually measured in terms of output units, such as annual tons of steel produced by a steel mill, or number of cars produced by a final assembly plant. In these cases, the outputs are homogeneous. In cases in which the output units are not homogeneous, other factors may be more appropriate measures, such as available labor hours of productive capacity in a machine shop that produces a variety of parts.

Materials, processes, and systems are the basic building blocks of manufacturing.

## 1.3 Engineering Materials Used in Manufacturing

Most engineering materials can be classified into one of three basic categories:

1. Metals
2. Ceramics, and
3. Polymers.

Their chemistries are different, their mechanical and physical properties are different, and these differences affect the manufacturing processes that can be used to produce products from them. In addition to the three basic categories, there is fourth material called – Composites (nonhomogeneous mixtures of the other three basic types rather than a unique category). The classification of the four groups is pictured in Figure 1.2.

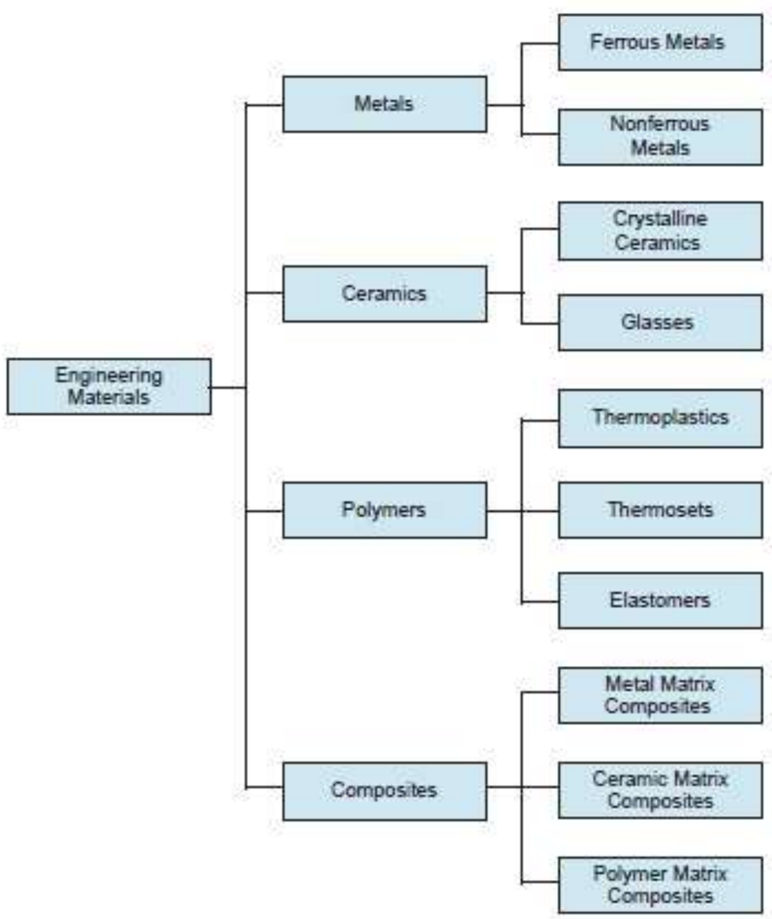


Figure 1.2: Classification of the four engineering materials.

### 1.3.1 Metals

Metals used in manufacturing are usually alloys, which are composed of two or more elements, with at least one being a metallic element. Metals and alloys can be divided into two basic groups: (1) ferrous and (2) non ferrous.

Ferrous Metals: Ferrous metals are based on iron; the group includes steel and cast iron. These metals constitute the most important group commercially, more than three fourths of the metal tonnage throughout the world. Pure iron has limited commercial use, but when alloyed with carbon, iron has more uses and greater commercial value than any other metal.

*Alloys of iron and carbon form steel and cast iron.*

***Steel*** can be defined as an iron–carbon alloy containing 0.02%to 2.11%carbon. It is the most important category within the ferrous metal group. Its composition often includes other alloying elements as well, such as manganese, chromium, nickel, and molybdenum, to enhance the properties of the metal. Applications of steel include construction (bridges, I-beams, and nails), transportation (trucks, rails, and rolling stock for railroads), and consumer products (automobiles and appliances).

***Cast iron*** is an alloy of iron and carbon (2% to 4%) used in casting (primarily sand casting). Silicon is also present in the alloy (in amounts from 0.5% to 3%), and other elements are often added also, to obtain desirable properties in the cast part. Cast iron is available in several different forms, of which gray cast iron is the most common; its applications include blocks and heads for internal combustion engines.

Nonferrous Metals Nonferrous metals include the other metallic elements and their alloys. In almost all cases, the alloys are more important commercially than the pure metals.

The nonferrous metals include the pure metals and alloys of aluminum, copper, gold, magnesium, nickel, silver, tin, titanium, zinc, and other metals.

### 1.3.2 Ceramics

A ceramic is defined as a compound containing metallic (or semi metallic) and nonmetallic elements. Typical nonmetallic elements are oxygen, nitrogen, and carbon. Ceramics include a variety of traditional and modern materials. Traditional ceramics, some of which have been used for thousands of years, include: clay (abundantly available, consisting of fine particles of hydrous aluminum silicates and other minerals used in making brick, tile, and pottery); silica (the basis for nearly all glass products); and alumina and silicon carbide (two abrasive materials used in grinding).Modern ceramics include some of the preceding materials, such as alumina, whosepropertiesareenhancedinvariouswaysthroughmodernprocessingmethods.

Newer ceramics include: carbides—metal carbides such as tungsten carbide and titanium carbide, which are widely used as cutting tool materials; and nitrides—metal and semimetal nitrides such as titanium nitride and boron nitride, used as cutting tools and grinding abrasives.

For processing purposes, ceramics can be divided into crystalline ceramics and glasses.

Different methods of manufacturing are required for the two types. Crystalline ceramics are formed in various ways from powders and then fired (heated to a temperature below the melting point to achieve bonding between the powders). The glass ceramics (namely, glass) can be melted and cast, and then formed in processes such as traditional glass blowing.

### 1.3.3 Polymers

A polymer is a compound formed of repeating structural units called mers, whose atoms share electrons to form very large molecules. Polymers usually consist of carbon plus one or more other elements, such as hydrogen, nitrogen, oxygen, and chlorine. Polymers are divided into three categories: (1) thermoplastic polymers, (2) thermosetting polymers, and (3) elastomers.

Thermoplastic polymers can be subjected to multiple heating and cooling cycles without substantially altering the molecular structure of the polymer. Common thermoplastics include polyethylene, polystyrene, polyvinylchloride, and nylon. Thermosetting polymers chemically transform (cure) into a rigid structure on cooling from a heated plastic condition; hence the name thermosetting. Members of this type include phenolics, amino resins, and epoxies.

Although the name thermosetting is used, some of these polymers cure by mechanisms other than heating. Elastomers are polymers that exhibit significant elastic behavior; hence the name elastomer. They include natural rubber, neoprene, silicone, and polyurethane.

### 1.3.4 Composites

Composites do not really constitute a separate category of materials; they are mixtures of the other three types. A composite is a material consisting of two or more phases that are processed separately and then bonded together to achieve properties superior to those of its constituents. The term phase refers to a homogeneous mass of material, such as an aggregation of grains of identical unit cell structure in a solid metal. The usual structure of a composite consists of particles or fibers of one phase mixed in a second phase, called the matrix.

Composites are found in nature (e.g., wood), and they can be produced synthetically.

The synthesized type is of greater interest here, and it includes glass fibers in a polymer matrix, such as fiber-reinforced plastic; polymer fibers of one type in a matrix of a second polymer, such as an epoxy-Kevlar composite; and ceramic in a metal matrix, such as a tungsten carbide in a cobalt binder to form a cemented carbide cutting tool.

Properties of a composite depend on its components, the physical shapes of the components, and the way they are combined to form the final material. Some composites combine high strength with light weight and are suited to applications such as aircraft components, car bodies, boat hulls, tennis rackets, and fishing rods. Other composites are strong, hard, and capable of maintaining these properties at elevated temperatures, for example, cemented carbide cutting tools.

## 1.4 Manufacturing Processes

A manufacturing process is a designed procedure that results in physical and/or chemical changes to a starting work material with the intention of increasing the value of that material.

A manufacturing process is usually carried out as a unit operation, which means that it is a single step in the sequence of steps required to transform the starting material into a final product. Manufacturing operations can be divided into two basic types: (1) processing operations and (2) assembly operations. A processing operation transforms a work material from one state of completion to a more advanced state that is closer to the final desired product. It adds value by changing the geometry, properties, or appearance of the starting material. In general, processing operations are performed on discrete workparts, but certain processing operations are also applicable to assembled items (e.g., painting a spot-welded car body). An assembly operation joins two or more components to create a new entity, called an assembly, subassembly, or some other term that refers to the joining process (e.g., a welded assembly is called a weldment). A classification of manufacturing processes is presented in Figure 1.3.

### 1.4.1 Processing Operations

A processing operation uses energy to alter a workpart's shape, physical properties, or appearance to add value to the material. The forms of energy include mechanical, thermal, electrical, and chemical. The energy is applied in a controlled way by means of machinery and tooling. Human energy may also be required, but the human workers are generally employed to control the machines, oversee the operations, and load and unload parts before and after each cycle of operation. A general model of a processing operation is illustrated in

Figure 1.1(a). Material is fed into the process, energy is applied by the machinery and tooling to transform the material, and the completed workpart exits the process. Most production operations produce waste or scrap, either as a natural aspect of the process (e.g., removing material, as in machining) or in the form of occasional defective pieces. It is an important objective in manufacturing to reduce waste in either of these forms.

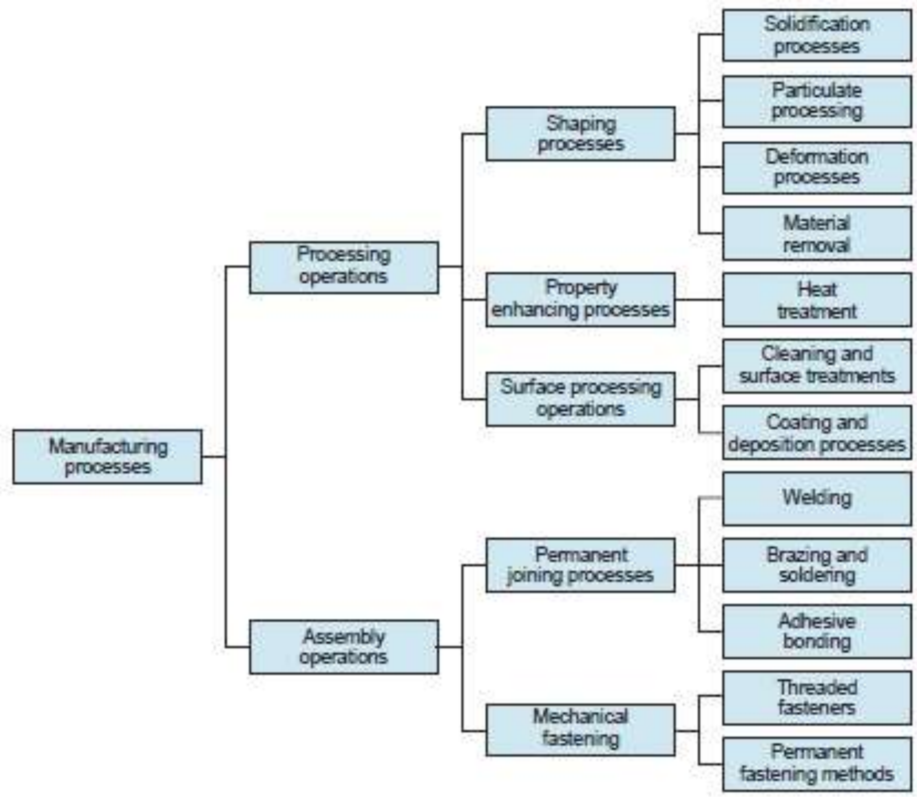


FIGURE 1.3: Classification of Manufacturing Processes.

More than one processing operation is usually required to transform the starting material into final form. The operations are performed in the particular sequence required to achieve the geometry and condition defined by the design specification.

Three categories of processing operations are distinguished:

i. Shaping operations
ii. Property-enhancing operations, and
iii. Surface processing operations.

Shaping operations alter the geometry of the starting work material by various methods. Common shaping processes include casting, forging, and machining. Property-enhancing operations add value to the material by improving its physical properties without changing its shape. Heat treatment is the most common example. Surface processing operations are performed to clean, treat, coat, or deposit material onto the exterior surface of the work. Common examples of coating are plating and painting.

### 1.4.2 Assembly Operations

The second basic type of manufacturing operation is assembly, in which two or more separate parts are joined to form a new entity. Components of the new entity are connected either permanently or semi permanently. Permanent joining processes include welding, brazing, soldering, and adhesive bonding. They form a joint between components that cannot be easily disconnected. Certain mechanical assembly methods are available to fasten two (or more) parts together in a joint that can be conveniently disassembled. The use of screws, bolts, and other threaded fasteners are important traditional methods in this category. Other mechanical assembly techniques are rivets, press fitting, and expansion fits.

## 1.5 Production Systems

To operate effectively, a manufacturing firm must have systems that allow it to efficiently accomplish its type of production. Production systems consist of people, equipment, and procedures designed for the combination of materials and processes that constitute a firm's manufacturing operations. Production systems can be divided into two categories:

i. Production facilities and
ii. Manufacturing support systems

Production facilities refer to the physical equipment and the arrangement of equipment in the factory. Manufacturing support systems are the procedures used by the company to manage production and solve the technical and logistics problems encountered in ordering materials, moving work through the factory, and ensuring that products meet quality.

## 1.6 Trends in Manufacturing

This section considers several trends that are affecting the materials, processes, and systems used in manufacturing. These trends are motivated by technological and economic factors occurring throughout the world. Their effects are not limited to manufacturing; they impact society as a whole. The discussion is organized into the following topic areas:

i. Lean production and Six Sigma
ii. Globalization
iii. Environmentally conscious manufacturing
iv. Microfabrication and nanotechnology.

### 1.6.1 Lean Production and Six Sigma

These are two programs aimed at improving efficiency and quality in manufacturing. They address the demands by customers for the products they buy to be both low in cost and high in quality. The reason why lean and Six Sigma are trends is because they are being so widely adopted by companies, especially in the United States.

Lean production is based on the Toyota Production System developed by Toyota Motors in Japan. Its origins date from the 1950s, when Toyota began using unconventional methods to improve quality, reduce inventories, and increase flexibility in its operations. Lean production can be defined simply as ''doing more work with fewer resources.'' It means that fewer workers and less equipment are used to accomplish more production in less time, and yet achieve higher quality in the final product. The underlying objective of lean production is the elimination of waste. In the Toyota Production System, the seven forms of waste in production are:

i. Production of defective parts
ii. Production of more parts than required
iii. Excessive inventories
iv. Unnecessary processing steps
v. Unnecessary movement of workers
vi. Unnecessary movement and handling of materials, and
vii. Workers waiting.

The methods used by Toyota to reduce waste include techniques for preventing errors, stopping a process when something goes wrong, improved equipment maintenance, involving workers in process improvements (so-called continuous improvement), and standardized work procedures. Six Sigma was started in the 1980s at Motorola Corporation in the United States. The objective was to reduce variability in the company's processes and products to increase customer satisfaction. Today, Six Sigma can be defined as ''a quality-focused program that utilizes worker teams to accomplish projects aimed at improving an organization's operational performance.''

### 1.6.2 Globalization and Outsourcing

The world is becoming more and more integrated, creating an international economy in which barriers once established by national boundaries have been reduced or eliminated. This has enabled a freer flow of goods and services, capital, technology, and people among regions and countries. Globalization is the term that describes this trend, which was recognized in the late 1980s and is now a dominant economic reality. Of interest here is that once underdeveloped nations such as China, India, and Mexico have developed their manufacturing infrastructures and technologies to a point where they are now important producers in the global economy.

The advantages of these three countries in particular are their large populations (therefore,

Large workforce pool) and low labor costs. Hourly wages are currently an order of magnitude or more higher in the United States than in these countries, making it difficult for domestic U.S. companies to compete in many products requiring a high labor content. Examples include garments, furniture, many types of toys, and electronic gear. The result has been a loss of manufacturing jobs in the United States and a gain of related work to these countries.

Globalization is closely related to outsourcing. In manufacturing, outsourcing refers to the use of outside contractors to perform work that was traditionally accomplished in house.

Outsourcing can be done in several ways, including the use of local suppliers. In this case the jobs remain in the United States. Alternatively, U.S. companies can outsource to foreign countries, so that parts and products once made in the United States are now made outside the country. In this case U.S. jobs are displaced. Two possibilities can be distinguished:

(1) offshore outsourcing, which refers to production in China or other overseas locations and transporting the items by cargo ship to the United States, and (2) near-shore outsourcing, which means the items are made in Canada, Mexico, or Central America and shipped by rail or truck into the United States.

China is a country of particular interest in this discussion of globalization because of its fast-growing economy, the importance of manufacturing in that economy, and the extent to which U.S. companies have outsourced work to China. To take advantage of the low labor rates, U.S. companies have outsourced much of their production to China (and other east Asian countries). Despite the logistics problems and costs of shipping the goods back into the United States, the result has been lower costs and higher profits for the outsourcing companies, as well as lower prices and a wider variety of available products for U.S. consumers. The downside has been the loss of well-paying manufacturing jobs in the United States. Another consequence of U.S. outsourcing to China has been a reduction in the relative contribution of the manufacturing sector to GDP. In the 1990s, the manufacturing industries accounted for about20%ofGDP in the United States. Today that contribution is less than 15%. At the same time, the manufacturing sector in China has grown (along with the rest of its economy), now accounting for almost 35%of Chinese GDP. Because the U.S.

GDP is roughly three times China's, the United States' manufacturing sector is still larger.

However, China is the world leader in several industries. Its tonnage output of steel is greater than the combined outputs of the next six largest steel producing nations (in order, Japan, United States, Russia, India, South Korea, and Germany).4 China is also the largest producer of metal castings, accounting for more tonnage than the next three largest producers (in order, United States, Japan, and India)