21.1 Introduction

Cutting processes remove material from the various surfaces of a workpiece by producing **chips**. Some of the more common cutting processes, illustrated in Fig. 21.1 (see also Fig. I.5e), are:

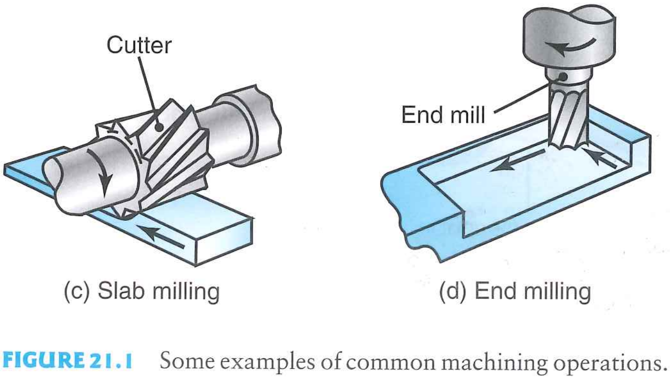

FIGURE 21.1 Some examples of common machining operations.

- **Turning**, in which the workpiece is rotated and a cutting tool removes a layer of material as the tool moves along its length, as shown in Fig. 21.1a
- **Cutting off**, in which the tool moves radially inward, and separates the piece on the right in Fig. 21.1b from the blank
- **Slab milling**, in which a rotating cutting tool removes a layer of material from the surface of the workpiece (Fig. 21.1c)
- **End milling**, in which a rotating cutter travels along a certain depth in the workpiece and produces a cavity (Fig. 21.1d)

In the turning process, illustrated in greater detail in Fig. 21.2, the cutting tool is set at a certain *depth of cut* (mm), and travels to the left with a certain speed as the workpiece rotates. The *feed*, or *feed rate*, is the distance the tool travels per unit revolution of the workpiece (mm/rev); this movement of the cutting tool produces a chip, which moves up the face of the tool.

In order to analyze this basic process in greater detail, a two-dimensional model of it is presented in Fig. 21.3a. In this *idealized* model, a cutting tool moves to the left along the workpiece at a constant velocity, V, and a depth of cut, t_o. A chip is produced ahead of the tool by plastic deformation, and shears the material continuously along the *shear plane*. This phenomenon can easily be demonstrated by slowly scraping the surface of a stick of butter lengthwise with a sharp knife, and observing how a chip is produced. Chocolate shavings used as decorations on cakes and pastries also are produced in a similar manner.

In comparing Figs. 21.2 and 21.3, note that the feed in turning is equivalent to t_o, and the depth of cut in turning is equivalent to the width of cut (i.e., the dimension perpendicular to the page). These dimensional relationships can be visualized by rotating Fig. 21.3 clockwise by 90°. With this brief introduction as a background, the cutting process will now be described in greater detail.

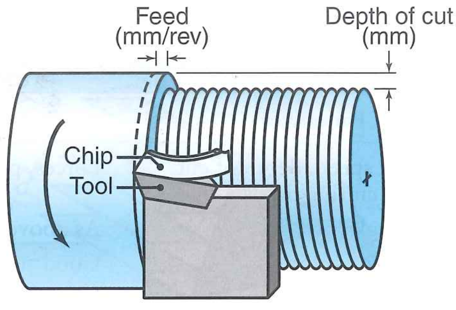

FIGURE 21.2 Schematic illustration of the turning operation, showing various features; surface finish is exaggerated to show feed marks.

21.2 Mechanics of Cutting

The factors that influence the cutting process are outlined in Table 21.1. In order to appreciate the contents of this table, note that the major *independent variables* in the basic cutting process are: (a) tool material and coatings, if any; (b) tool shape, surface finish, and sharpness; (c) workpiece material and its processing history; (d) cutting speed, feed, and depth of cut; (e) cutting fluids, if any; (f) characteristics of the machine tool; and (g) the type of work-holding device and fixturing.

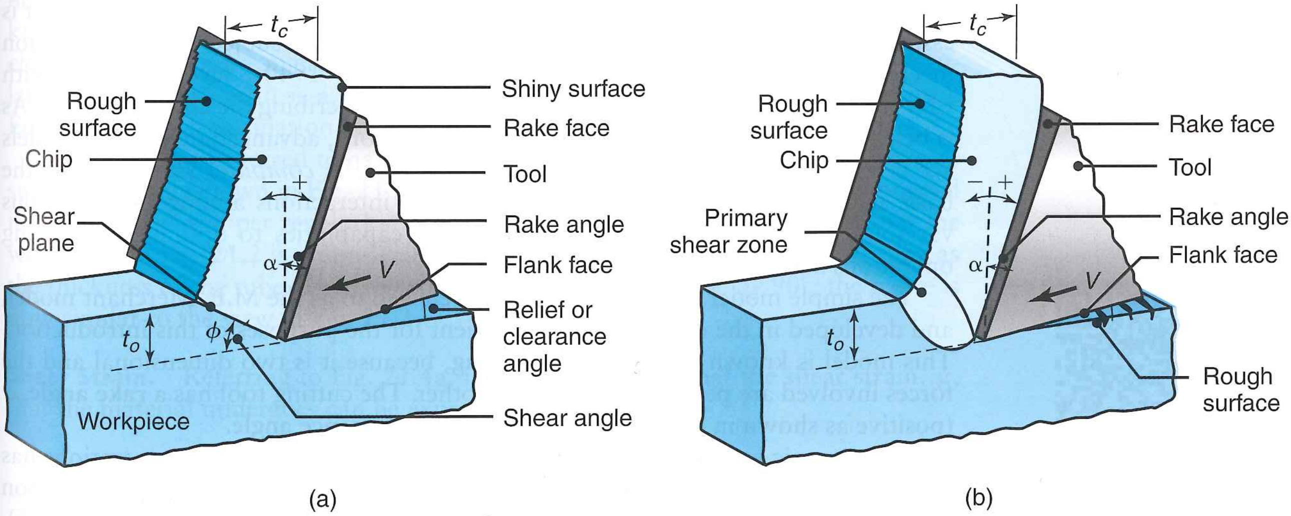

FIGURE 21.3 Schematic illustration of a two-dimensional cutting process, also called orthogonal cutting: (a) Orthogonal cutting with a well-defined shear plane, also known as the M.E. Merchant model. Note that the tool shape, the depth of cut, t_o, and the cutting speed, V, are all independent variables. (b) Orthogonal cutting without a well-defined shear plane.

TABLE 21.1

Factors Influencing Machining Operations

Parameter	Influence and interrelationship
Cutting speed, depth of cut, feed, cutting fluids	Forces, power, temperature rise, tool life, type of chip, surface finish, and integrity
Tool angles	As above; influence on chip flow direction; resistance to tool wear and chipping
Continuous chip	Good surface finish; steady cutting forces; undesirable, especially in modern machine tools
Built-up edge chip	Poor surface finish and integrity; if thin and stable, edge can protect tool surfaces
Discontinuous chip	Desirable for ease of chip disposal; fluctuating cutting forces; can affect surface finish and cause vibration and chatter
Temperature rise	Influences tool life, particularly crater wear and dimensional accuracy of workpiece; may cause thermal damage to workpiece surface
Tool wear	Influences surface finish and integrity, dimensional accuracy, temperature rise, and forces and power
Machinability	Related to tool life, surface finish, forces and power, and type of chip produced

Dependent variables in cutting are those that are influenced by changes made in the independent variables listed above. These include: (a) type of chip produced; (b) force and energy dissipated during cutting; (c) temperature rise in the workpiece, the tool, and the chip; (d) tool wear and failure; and (e) surface finish and surface integrity of the workpiece.

The importance of establishing *quantitative* relationships among the independent and dependent variables in machining can best be appreciated by considering some typical questions to be posed: Which of the independent variables should be changed first, and to what extent, if (a) the surface finish of the workpiece being machined is unacceptable, (b) the cutting tool wears rapidly and becomes dull, (c) the workpiece becomes very hot, and (d) the tool begins to vibrate and chatter.

In order to understand these phenomena and respond to the question posed, it is essential to first study the mechanics of chip formation. The subject of chip formation mechanics has been studied extensively since the early 1940s. Several models, with varying degrees of complexity, have been proposed describing the cutting process. As is being done in many other manufacturing operations, advanced machining models are being continuously developed, including especially *computer simulation* of the basic machining process. Studying the complex interactions among the numerous variables involved, in turn, helps develop the capabilities to optimize machining operations and minimize costs.

The simple model shown in Fig. 21.3a, referred to as the M.E. Merchant model, and developed in the early 1940s, is sufficient for the purposes of this introduction. This model is known as **orthogonal cutting**, because it is two dimensional and the forces involved are perpendicular to each other. The cutting tool has a **rake angle**, α (positive as shown in the figure), and a **relief** or **clearance angle**.

Microscopic examination of chips produced in actual machining operations has revealed that they are produced by *shearing* (as modeled in Fig. 21.4a), a phenomenon similar to the movement in a deck of cards sliding against each other (see also Fig. 1.6). Shearing takes place within a **shear zone** (usually along a well-defined plane, referred to as the **shear plane**) at an angle ϕ (called the **shear angle**). Below the shear plane, the workpiece remains undeformed; above it, the chip (already formed) moves up the rake face of the tool. The dimension d is highly exaggerated in the figure to show the mechanism involved in chip formation. This dimension, in reality, has been found to be only on the order of 10^{-2} to 10^{-3} mm.

Some materials, notably cast irons at low speeds, do not shear along a well-defined plane, but instead shear within a zone, as shown in Fig. 21.3b. The shape and size of this zone is important in the machining operation, as will be discussed in Section 21.2.1.

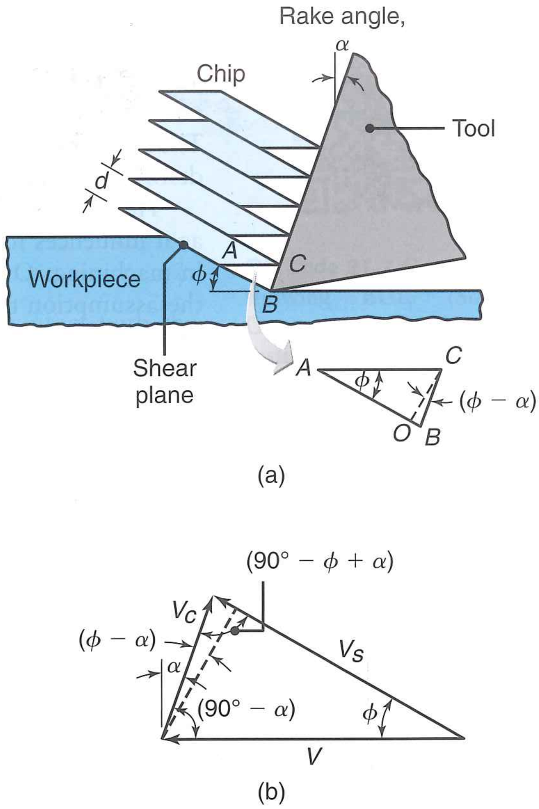

FIGURE 21.4 (a) Schematic illustration of the basic mechanism of chip formation by shearing. (b) Velocity diagram showing angular relationships among the three speeds in the cutting zone.