Manufacturing / Manufacturing Process/ Material Removal Processes

Problem Set

No problem set

Examples

video

Notes

video

Material Removal Processe

(Theory of Metal Machining)

The *material removal processes* are a family of shaping operations in which excess material is removed from a starting workpart so that what remains is the desired final geometry. The "family tree" is shown in Figure 5.1. The most important branch of the family is *conventional machining*, in which a sharp cutting tool is used to mechanically cut the material to achieve the desired geometry. The three principal machining processes are turning, drilling, and milling. The "other machining operations" in Figure 5.1 include shaping, planing, broaching, and sawing.

Another group of material removal processes is the *abrasive processes*, which mechanically remove material by the action of hard, abrasive particles. This process group includes grinding. The "other abrasive processes" in Figure 5.1 include honing, lapping, and super finishing. Finally, there are the *nontraditional processes*, which use various energy forms other than a sharp cutting tool or abrasive particles to remove material. The energy forms include mechanical, electrochemical, thermal, and chemical.

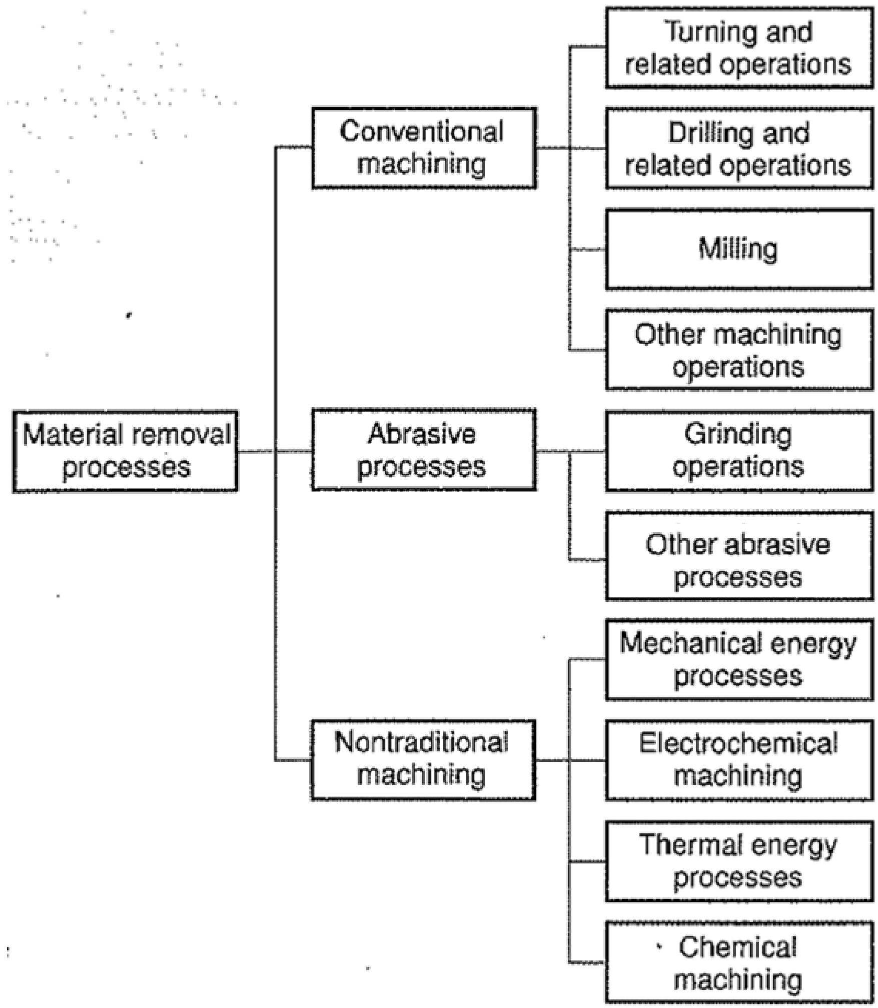

Figure 5.1 Classification of material removal processes.

Machining is a manufacturing process in which a sharp cutting tool is used to cut away material to leave the desired part shape. The predominant cutting action in machining involves shear deformation of the work material to form a chip; as the chip is removed, a new surface is exposed. Machining is most frequently applied to shape metals. The process is illustrated in the diagram of Figure 5.2.

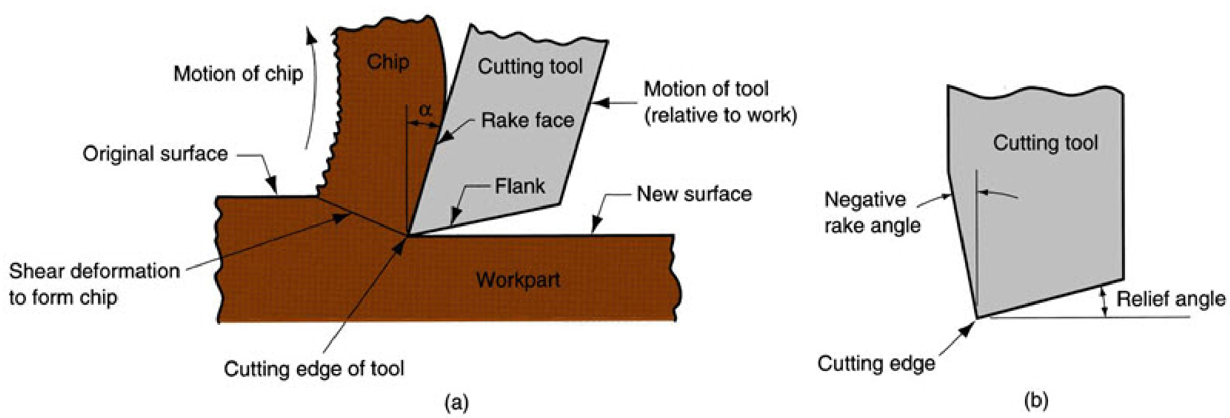

Figure 5.2 (a) A cross-sectional view of the machining process. (b) Tool with negative rake angle; compare with positive take angle in (a).

Machining is one of the most important manufacturing processes. Machining is important commercially and technologically for several reasons:

- *Variety of work materials. Machining can be applied to a wide variety of work materials. Virtually all solid metals can be machined. Plastics and plastic composites can also be cut by machining. Ceramics pose difficulties because of their high hardness and brittleness; however, most ceramics can be successfully cut by the abrasive machining processes.*
- *Variety of part shapes and geometric features. Machining can be used to create any regular geometries, such as flat planes, round holes, and cylinders. By introducing variations in tool shapes and tool paths, irregular geometries can be created, such as screw threads and T-slots. By combining several machining operations in sequence, shapes of almost unlimited complexity and variety can be produced.*
- *Dimensional accuracy. Machining can produce dimensions to very close tolerances.*
- *Good surface finishes. Machining is capable of creating very smooth surface finishes.*

On the other hand, certain disadvantages are associated with machining and other material removal processes:

- *Wasteful of material. Machining is inherently wasteful of material. The chips generated in a machining operation are wasted material. Although these chips can usually be recycled, in terms of the unit operation, the material that is removed is waste.*
- *Time consuming. A machining operation generally takes more time to shape a given part than alternative shaping processes such as casting or forging.*

Machining is generally performed after other manufacturing processes such as casting or bulk deformation (e.g., forging, bar drawing). The other processes create the general shape of the starting workpart, and machining provides the final geometry, dimensions, and finish.

OVERVIEW OF MACHINING TECHNOLOGY

Machining is not just one process; it is a group of processes. The common feature is the use of a cutting tool to form a chip that is removed from the workpart. To perform the operation, relative motion is required between the tool and work. This relative motion is achieved in most machining operations by means of a primary motion, called the cutting speed, and a secondary motion, called the feed. The shape of the tool and its penetration into the work surface, combined with these motions, produces the desired shape of the resulting work surface.

Types of Machining Operation There are many kinds of machining operations, each of which is capable of generating a certain part geometry and surface texture. In this MODULE it is appropriate to identify and define the three most common types: turning, drilling, and milling, illustrated in Figure 5.3.

In turning, a cutting tool with a single cutting edge is used to remove material from a rotating workpiece to generate a cylindrical shape, as in Figure 5.3(a). The speed motion in turning is provided by the rotating workpart, and the feed motion is achieved by the cutting tool moving slowly in a direction parallel to the axis of rotation of the workpiece.

Drilling is used to create a round hole. It is accomplished by a rotating tool that typically has two cutting edges. The tool is fed in a direction parallel to its axis of rotation into the workpart to form the round hole, as in Figure 5.3(b).

In milling, a rotating tool with multiple cutting edges is moved slowly relative to the material to generate a plane or straight surface. The direction of the feed motion is perpendicular to the tool's axis of rotation. The speed motion is provided by the rotating milling cutter. The two basic forms of milling are peripheral milling and face milling, as in Figure 5.3 (c) and (d).

ther conventional machining operations include shaping, planing, broaching, and sawing. Also, grinding and similar abrasive operations are often included within the category of machining. These processes commonly follow the conventional machining operations and are used to achieve a superior surface finish on the workpart.

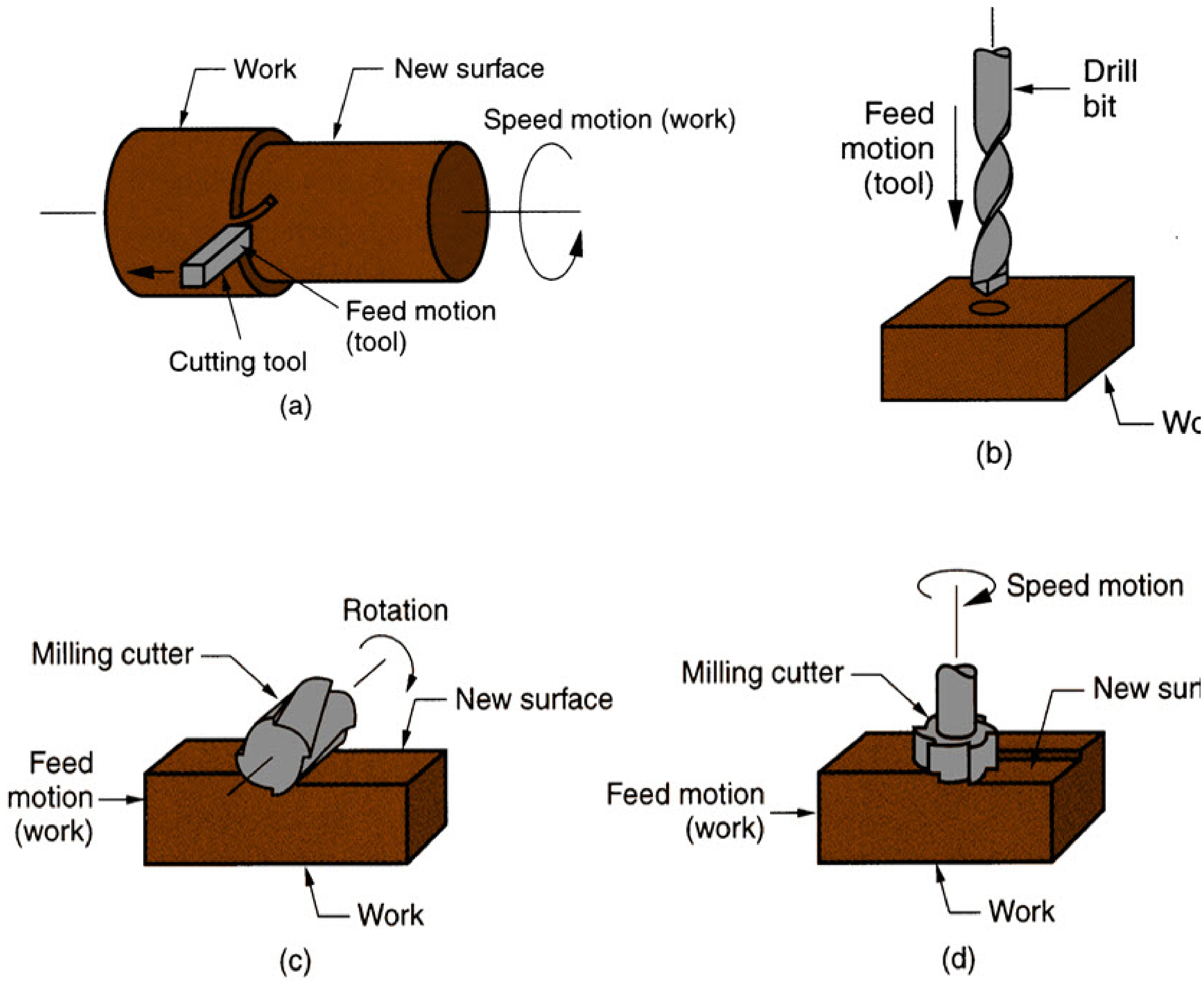

Figure 5.3 The three most common types of machining processes: (a) turning, (b) drilling, and two forms of milling: (c) peripheral milling, and (d) face milling.

The Cutting Tool

A cutting tool has one or more sharp cutting edges and is made of a material that is harder than the work material. The cutting edge serves to separate a chip from the parent work material, as in Figure 5.2. Connected to the cutting edge are two surfaces of the tool: the rake face and the flank. The rake face, which directs the flow of the newly formed chip, is oriented at a certain angle called the rake angle. It is measured relative to a plane perpendicular to the work surface. The rake angle can be positive, as in Figure 5.2(a), or negative as in (b). The flank of the tool provides a clearance between the tool and the newly generated work surface, thus protecting the surface from abrasion, which would degrade the finish. This flank surface is oriented at an angle called the relief angle.

Most cutting tools in practice have more complex geometries than those in Figure 5.2. There are two basic types, examples of which are illustrated in Figure 5.4: (a) single-point tools and (b) multiple-cutting-edge tools. A single-point tool has one cutting edge and is used for operations such as turning. In addition to the tool features shown in Figure 5.2, there is one tool point form which the name of this cutting tool is derived. During machining, the point of the tool penetrates below the original work surface of the workpart. The point is usually rounded to a certain radius, called the nose radius.

Multiple-cutting-edge tools have more than one cutting edge and usually achieve their motion relative to the workpart by rotating. Drilling and milling use rotating multiple-cutting-edge tools. Figure 5.4 (b) shows a helical milling cutter used in peripheral milling. Although the shape is quite different from a single-point tool, many elements of tool geometry are similar.

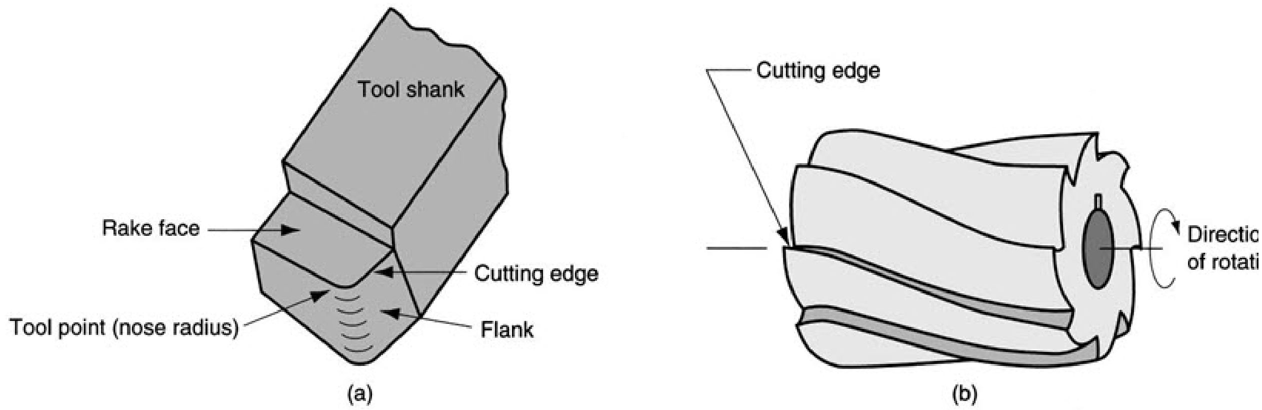

Figure 5.4 (a) A single-point tool showing rake face, flank, and tool point; and (b) a helical milling cutter, representative of tools with multiple cutting edges

Cutting Conditions

Relative motion is required between the tool and work to perform a machining operation. The primary motion is accomplished at a certain cutting speed v. In addition, the tool must be moved laterally across the work. This is a much slower motion, called the feed f. The remaining dimension of the cut is the penetration of the cutting tool below the original work surface, called the depth of cut d. Collectively, speed, feed, and depth of cut are called the cutting conditions. They form the three dimensions of the machining process, and for certain operations (e.g., most single-point tool operations) their product can be used to obtain the material removal rate for the process:

$$R_{MR} = v\,f\,d$$

Where R_{MR} = material removal rate, mm^3/s; v = cutting speed, m/s which must be converted to mm/s; f = feed, mm; and d = depth of cut, mm.

The cutting conditions for a turning operation are depicted in Figure 5.5. Typical units used for cutting speed are m/s. Feed in turning is expressed in mm/rev, and depth of cut is expressed in mm. In other machining operations, interpretations of the cutting conditions may differ. For example, in a drilling operation, depth is interpreted as the depth of the drilled hole.

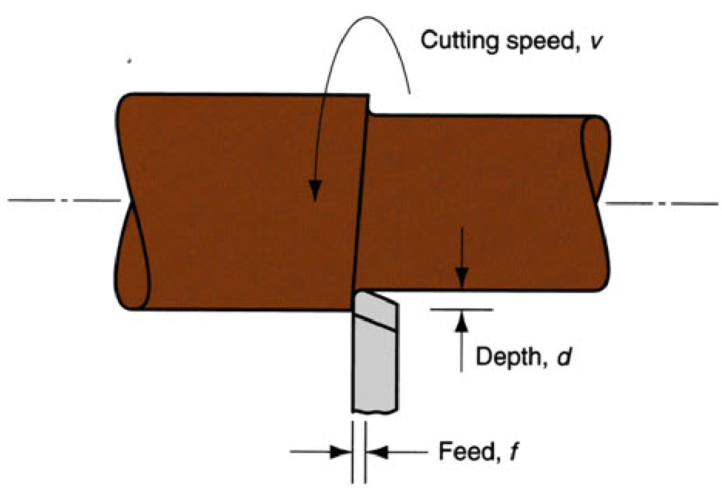

Figure 5.5 Cutting speed, feed, and depth of cut in turning.

Machining operations usually divided into two categories, distinguished by purpose and cutting conditions: roughing cuts and *finishing cuts. Roughing cuts are used to remove large amounts of material from the starting workpart as rapidly as possible, in order to produce a shape close to the desired form, but leaving some material on the piece for a subsequent finishing operation. Finishing cuts are used to complete the part and achieve the final dimensions, tolerances, and surface finish. In production machining jobs, one or more roughing cuts are usually performed on the work, followed by one or two finishing cuts. Roughing operations are performed at high feeds and depths – feeds of 0.4 – 1.25 mm/rev and depths of 2.5 – 20 mm are typical. Finishing operations are carried out at low feeds and depths – feeds of 0.125 – 0.4 mm/rev and depths of 0.75 – 2.0 mm are typical. Cutting speeds are lower in roughing than in finishing.*

A cutting fluid is often applied to the machining operation to cool and lubricate the cutting tool.

Machine Tools

A machine tool is used to hold the workpart, position the tool relative to the work, and provide power for the machining process at the speed, feed, and depth that have been set. By controlling the tool, work, and cutting conditions, machine tools permit parts to be made with great accuracy and repeatability, to tolerances of 0.025 mm and better. The term machine tool applies to any power-driven machine that performs a machining operation, including grinding. The term is also applied to machines that perform metal forming and pressworking operations.

The traditional machine tools used to perform turning, drilling, and milling are lathes, drill presses, and milling machines, respectively. Conventional machine tools are usually tended by a human operator, who loads and unloads the workparts, changes cutting tools, and sets the cutting conditions. Many modern machine tools are designed to accomplish their operations with a form of automation called computer numerical control.

Types of chip in Machining

Formation of the chip depends on the type of material being machined and the cutting conditions of the operation. Four basic types of chip can be distinguished, illustrated in Figure 5.6.

(a) *Discontinuous chip. When relatively brittle materials (e.g., cast irons) are machined at low cutting speeds, the chips often form into separate segments (sometimes the segments are loosely attached). This tends to impart an irregular texture to the machined surface. High tool – chip friction and large feed and depth of cut promote the formation of this chip type.*

(b) *Continuous chip. When ductile work materials are cut at high speeds and relatively small feeds and depths, long continuous chips are formed. A good surface finish typically results when this chip type is formed. A sharp cutting edge on the tool and low tool – chip friction encourage the formation of continuous chips. Long, continuous chips (as in turning) can cause problems with regard to chip disposal and/or tangling about the tool. To solve these problems, turning tools are often equipped with chip breakers.*

(c) *Continuous chip with built-up edge. When machining ductile materials at low-to-medium cutting speeds, friction between tool and chip tends to cause portions of the work material to adhere to the rake face of the tool near the cutting edge. This formation is called a built-up edge (BUE). The formation of a BUE is cyclical; it forms and grows, then becomes unstable and breaks off. Much of the detached BUE is carried away with the chip, sometimes taking portions of the tool rake face with it, which reduces the life of the cutting tool. Portions of the detached BUE that are not carried off with the chip become imbedded in the newly created work surface, causing the surface to become rough.*

The preceding chip types were first classified by Ernst in the late 1930s. Since then, the available metals used in machining, cutting tool materials, and cutting speeds have all increased, and a fourth chip type has been identified:

(d) *rrated chips (the term shear-localized is also used for this fourth chip type). These chips are semi-continuous in the sense that they possess a saw-tooth appearance that is produced by a cyclical chip formation of alternating high shear strain followed by low shear strain. This fourth type of chip is most closely associated with certain difficult-to-machine metals such as titanium alloys, nickel-base super alloys, and austenitic stainless steels when they are machined at higher cutting speeds. However, the phenomenon is also found with more common work metals (e.g., steels) when they are cut at high speeds.*

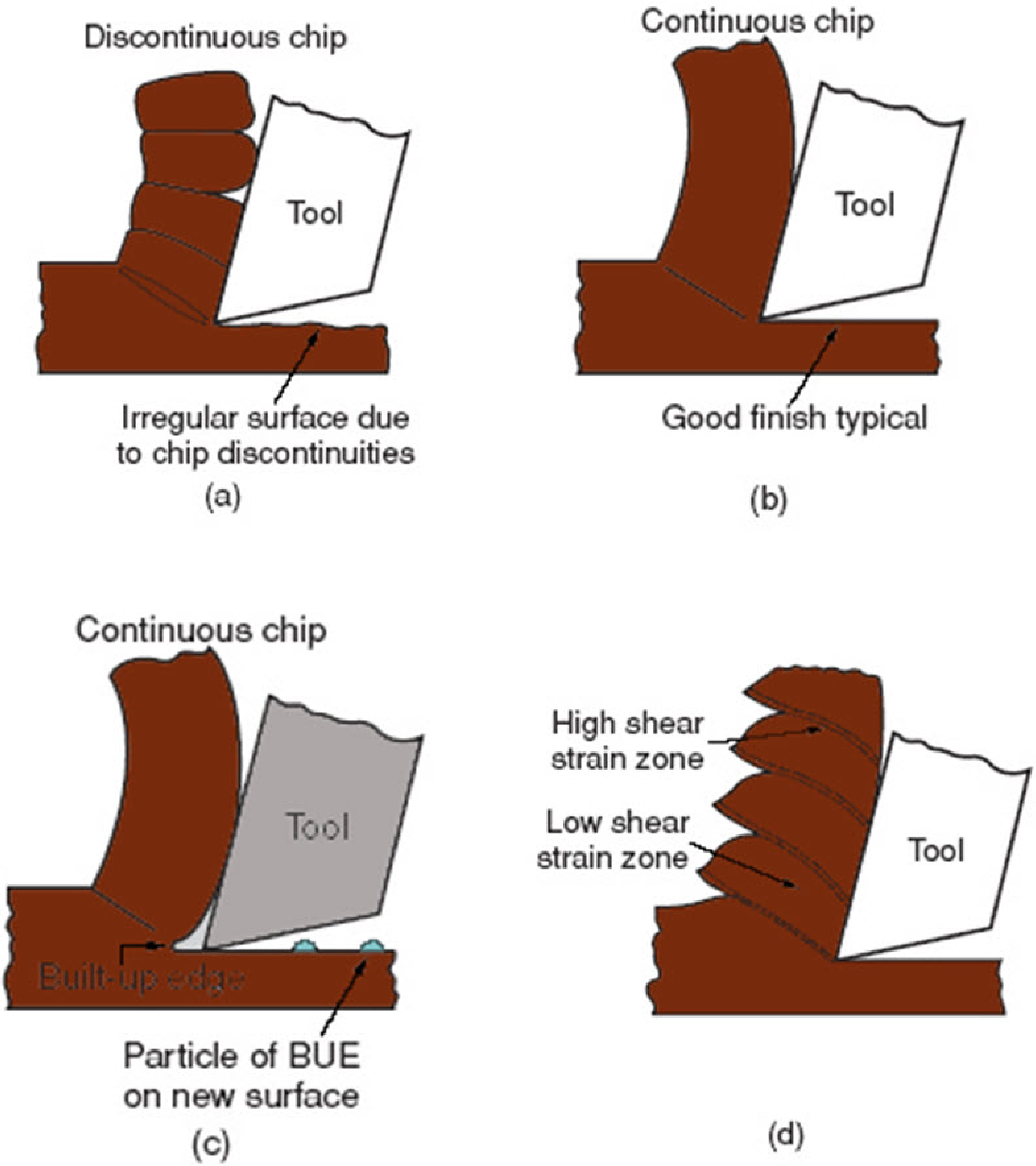

Figure 5.6 Four types of chip formation in metal cutting: (a) discontinuous, (b) continuous, (c) continuous with built-up edge, (d) serrated.

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