Chapter 8

Material-Removal Processes: Cutting

Questions

8.1 Explain why the cutting force, F_c, increases with increasing depth of cut and decreasing rake angle.

(a) Increasing the depth of cut means more material being removed per unit time. Thus, all other parameters remaining constant, the cutting force has to increase linearly because the energy requirement increases linearly.

(b) As the rake angle decreases, the shear angle decreases and hence the shear strain increases. Therefore, the energy per unit volume of material removed increases, thus the cutting force has to increase. Note that the rake angle also has an effect on the frictional energy (see Table 8.1 on p. 430).

8.2 What are the effects of performing a cutting operation with a dull tool tip? A very sharp tip?

There are several effects of a dull tool. Note that a dull tool is one having an increased tip radius (see Fig. 8.28 on p. 449). As the tip radius increases (i.e., as the tool dulls), the cutting force increases due to the fact that the effective rake angle is now decreased. In fact, shallow depths of cut may not be possible. Another effect is the possibility for surface residual stresses, tearing, and cracking of the machined surface, due to severe surface deformation and the heat generated by the dull tool tip rubbing against this surface. Dull tools also increase the tendency for BUE formation, which leads to poor surface finish.

8.3 Describe the trends that you observe in Tables 8.1 and 8.2.

By the student. A review of Tables 8.1 and 8.2 on pp. 430–431 indicates certain trends that are to be expected, including:

(a) As the rake angle decreases, the shear strain and hence the specific energy increase.

(b) Cutting force also increases with decreasing rake angle;

(c) Shear plane angle decreases with increasing rake angle.

8.4 To what factors would you attribute the large difference in the specific energies within each group of materials shown in Table 8.3?

The differences in specific energies seen in Table 8.3 on p. 435, whether among different materials or within types of materials, can basically be attributed to differences in the mechanical and physical properties of these materials, which affect the cutting operation. For example, as strength increases, so does the total specific energy. Differences in tool-chip interface friction characteristics would also play a significant role. Physical properties, such as thermal

conductivity and specific heat, both of which increase cutting temperatures as they decrease, could be responsible for such differences. These points are supported when one closely examines this table and observes that the ranges for materials such as steels, refractory alloys, and high-temperature alloys are large, in agreement with our knowledge of the great variety of these classes of materials.

8.5 Describe the effects of cutting fluids on chip formation. Explain why and how they influence the cutting operation.

By the student. In addition to the effects discussed in Section 8.7 starting on p. 464, cutting fluids influence friction at the tool-chip interface, thus affecting the shear angle and chip thickness. These, in turn, can influence the type of chip produced. Also, note that with effective cutting fluids the built-up edge can be reduced or eliminated.

8.6 Under what conditions would you discourage the use of cutting fluids? Explain.

By the student. The use of cutting fluids could be discouraged under the following conditions:

(a) If the cutting fluid has any adverse effects on the workpiece and/or machine-tool components, or on the overall cutting operation.

(b) In interrupted cutting operations, such as milling, the cutting fluid will, by its cooling action, subject the tool to large fluctuations in temperature, possibly causing thermal fatigue of the tool, particularly in ceramics.

8.7 Give reasons that pure aluminum and copper are generally rated as easy to machine.

There are several reasons that aluminum and copper are easy to machine. First, they are relatively soft, hence cutting forces and energy are low compared to many other materials. Furthermore, they are good thermal conductors. Also, they are ductile and can withstand the strains in cutting and still develop continuous chips. These materials do not generally form a built-up edge, depending on cutting parameters.

8.8 Can you offer an explanation as to why the maximum temperature in cutting is located at about the middle of the tool-chip interface? (*Hint:* Note that there are two principal sources of heat: the shear plane and the tool-chip interface.)

It is reasonable that the maximum temperature in orthogonal cutting is located at about the middle of the tool-chip interface. The chip reaches high temperatures in the primary shear zone; the temperature would decrease from then on as the chip climbs up the rake face of the tool. If no frictional heat was involved, we would thus expect the highest temperature to occur at the shear plane. However, recall that friction at the tool-chip interface also increases the temperature. After the chip is formed it slides up the rake face and temperature begins to build up. Consequently, the temperature due only to frictional heating would be highest at the end of the tool-chip contact. These two opposing effects are additive, and as a result the temperature is highest somewhere in between the tip of the tool and the end of contact zone.

8.9 State whether or not the following statements are true for orthogonal cutting, explaining your reasons: (a) For the same shear angle, there are two rake angles that give the same cutting ratio. (b) For the same depth of cut and rake angle, the type of cutting fluid used has no influence on chip thickness. (c) If the cutting speed, shear angle, and rake angle are known, the chip velocity can be calculated. (d) The chip becomes thinner as the rake angle increases. (e) The function of a chip breaker is to decrease the curvature of the chip.

(a) To show that for the same shear angle there are two rake angles and given the same cutting ratio, recall the definition of the cutting ratio as given by Eq. (8.1) on p. 420. Note that the numerator is constant and that the cosine of a positive and negative angle for the denominator has the same value. Thus, there are two rake angles that give the same r, namely a rake angle, α, greater than the shear angle, ϕ, and a rake angle smaller than the shear angle by the same amount.

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relatively small or large depth of cut? Explain your reasons.

Because oxides are generally hard and abrasive (see p. 146), light cuts will cause the tool to wear rapidly, and thus it is highly desirable to cut right through the oxide layer during the first pass. Note that an uneven round bar indicates significant variations in the depth of cut being taken; thus, depending on the degree of eccentricity, it may not always be possible to do so since this can lead to self-excited vibration and chatter.

8.69 Does the force or torque in drilling change as the hole depth increases? Explain.

Both the torque and the thrust force generally increase as the hole depth increases, although the change is more pronounced on the torque. Because of elastic recovery along the cylindrical surface of the hole, there is a normal stress exerted on the surface of the drill while in the hole. Consequently, the deeper the hole, the larger the surface area and thus the larger the force acting on the periphery of the drill, leading to a significant increase in torque.

8.70 Explain the advantages and limitations of producing threads by forming and cutting, respectively.

By the student. Thread rolling is described in Section 6.3.5. The main advantages of thread rolling over thread cutting are the speeds involved (thread rolling is a very high-production-rate operation). Also, the fact that the threads undergo extensive cold working will lead to stronger work-hardened threads. Cutting continues to be used for making threads because it is a very versatile operation and much more economical for low production runs (since expensive dies are not required). Note that internal threads also can be rolled, but this is not nearly as common as machining and can be a difficult operation to perform.

8.71 Describe your observations regarding the contents of Tables 8.8, 8.10, and 8.11.

By the student. Note, for example, that the side rake angle is low for the ductile materials such as thermoplastics, but is high for materials more difficult to machine, such as refractory alloys and some cast irons with limited ductility. Similar observations can be made for the drill geometries and the point angle.

8.72 The footnote to Table 8.10 states that as the depth of the hole increases, speeds and feeds should be reduced. Why?

As hole depth increases, elastic recovery in the workpiece causes normal stresses on the surface of the drill, thus the stresses experienced by the drill are higher than they are in shallow holes. These stresses, in turn, cause the torque on the drill to increase and may even lead to its failure. Reduction in feeds and speeds can compensate for these increases. (See also answer to Question 8.69.)

8.73 List and explain the factors that contribute to poor surface finish in machining operations.

By the student. As an example, one factor is explained by Eq. (8.35) on p. 449, which gives the roughness in a process such as turning. Clearly, as the feed increases or as the tool nose radius decreases, roughness will increase. Other factors that affect surface finish are built-up edge (see, for example, Figs. 8.4 and 8.6), dull tools or tool-edge chipping (see Fig. 8.28), or vibration and chatter (Section 8.11.1).

8.74 Make a list of the machining operations described in this chapter, according to the difficulty of the operation and the desired effectiveness of cutting fluids. (*Example:* Tapping of holes is a more difficult operation than turning straight shafts.)

By the student. Tapping is high in operational severity because the tool produces chips that are difficult to dispose of. Tapping has a very confined geometry, making effective lubrication and cooling difficult. Turning, on the other hand, is relatively easy.

8.75 Are the feed marks left on the workpiece by a face-milling cutter segments of a true circle? Explain with appropriate sketches.

By the student. Note that because there is always movement of the workpiece in the feed direction, the feed marks will not be segments of true circles.

8.76 What determines the selection of the number of teeth on a milling cutter? (See, for example, Figs. 8.53 and 8.55.)

The number of teeth will affect the surface finish produced, as well as vibrations and chatter, depending on the machine-tool structural characteristics. The number is generally chosen to achieve the desired surface finish at a given set of machining parameters. Note also that the finer the teeth, the greater the tendency for chip to clog. At many facilities, the choice of a cutter may simply be what tooling is available in the stock room.

8.77 Explain the technical requirements that led to the development of machining and turning centers. Why do their spindle speeds vary over a wide range?

By the student. See Section 8,11. Briefly, machining centers, as a manufacturing concept, serve two basic purposes:

(a) save time by rapid tool changes,

(b) eliminating part handling and mounting in between operations, and

(c) rapid changeover for machining different parts in small lots.

Normally, much time would be spent transferring and handling the workpiece between different machine tools. Machining centers eliminate or greatly reduce the need for part handling and, consequently, reduce manufacturing time and costs.

8.78 In addition to the number of components, as shown in Fig. 8.74, what other factors influence the rate at which damping increases in a machine tool? Explain.

By the student. The most obvious factors are the damping characteristics of the machine-tool structure and its foundation; vibration isolating pads are commonly installed under machine tools. The type and quality of joints, as well as the quality of the sliding surfaces and their lubrication, and the manner in which the individual components are assembled also have a significant effect. (See Section 8.11.1.)

8.79 Why is thermal expansion of machine-tool components important? Explain, with examples.

When high precision is required, thermal distortion is very important and must be eliminated or minimized. This is a serious concern, as even a few degrees of temperature rise can be significant and can compromise dimensional accuracy. The student should elaborate further.

8.80 Would using the machining processes described in this chapter be difficult on nonmetallic or rubber like materials? Explain your thoughts, commenting on the influence of various physical and mechanical properties of workpiece materials, the cutting forces involved, the parts geometries, and the fixturing required.

By the student. Rubber like materials are difficult to machine mainly because of their low elastic modulus and very large elastic strains that they can undergo under external forces. Care must be taken to properly support the workpiece and minimize the cutting forces. Note also that these materials become stiffer with lower temperatures, which suggests an effective cutting strategy and chilling of the workpiece.

8.81 The accompanying illustration shows a part that is to be machined from a rectangular blank. Suggest the type of operations required and their sequence, and specify the machine tools that are needed.

Stepped cavity Drilled and tapped holes
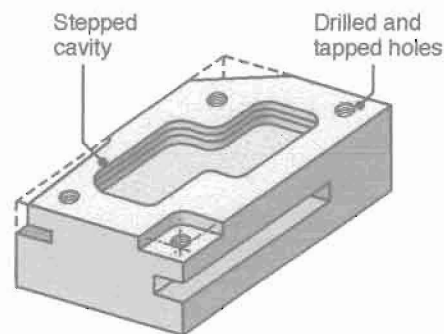
By the student. The main challenge with the part shown is in designing a fixture that allows all of the operations to be performed without interference. Clearly, a milling machine will be required for milling the stepped cavity and the

slots; the holes could be produced in the milling machine as well, although a drill press may be used instead. Note that one hole is drilled on a milled surface, ~~so drilling and tapping have to follow milling~~. If the surface finish on the exterior is not critical, a chuck or vise can be used to grip the surface at the corners, which is plausible if the part has sufficient height. The grips usually have rough surfaces, so they will leave marks which will be more pronounced in aluminum than in stainless steels.
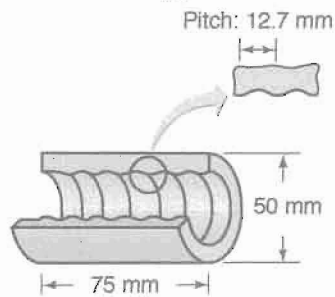
8.82 Select a specific cutting-tool material and estimate the machining time for the parts shown in the accompanying three figures: (a) pump shaft, stainless steel; (b) ductile (nodular) iron crankshaft; (c) 304 stainless-steel tube with internal rope thread.
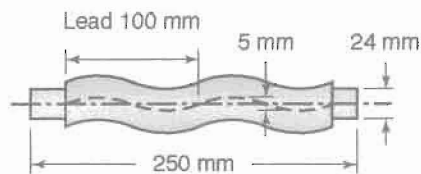
(a)
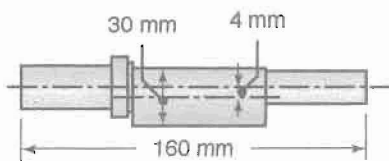
(b)

(c)

By the student. Students should address the methods and machinery required to produce these components, recognizing the economic implications of their selection of materials.

8.83 Why is the machinability of alloys generally difficult to assess?

The machinability of alloys is difficult to assess because of the wide range of chemical, mechanical, and physical properties that can be achieved in alloys, as well as their varying amounts of alloying elements. Some mildly alloyed materials may be machined very easily, whereas a highly alloyed material may be brittle, abrasive, and thus difficult to machine.

8.84 What are the advantages and disadvantages of dry machining?

By the student. See Section 8.7.2. The advantages of dry machining include:

(a) no lubricant cost;

(b) no need for lubricant disposal;

(c) no environmental concerns associated with lubricant disposal;

(d) no need to clean the workpiece, or at least the cleaning is far less difficult.

The disadvantages include:

(a) possibly higher tool wear;

(b) oxidation and discoloration of the work-piece surface since no lubricant is present to protect surfaces;

(c) possibly higher thermal distortion of the workpiece, and

(d) washing away chips may become difficult.

8.85 Can high-speed machining be performed without the use of cutting fluids? Explain.

This can be done, using appropriate tool materials and processing parameters. Recall that in high speed machining, most of the heat is conveyed from the cutting zone through the chip, so the need for a cutting fluid is less.

8.86 If the rake angle is 0°, then the frictional force is perpendicular to the cutting direction and, therefore, does not contribute to machining power requirements. Why, then, is there an increase in the power dissipated when machining with a rake angle of, say, 20°?

Lets first note that although the frictional force, because of its vertical position, does not directly affect the cutting power at a rake angle of zero,