Chapter 21

Fundamentals of Machining

QUALITATIVE PROBLEMS

21.14 Are the locations of maximum temperature and crater wear related? If so, explain why.

Although various factors can affect crater wear, the most significant factors in crater wear are diffusion (a mechanism whereby material is removed from the rake face of the tool) and the degree of chemical affinity between the tool and the chip. Thus, the higher the temperature, the higher the wear. Referring collectively to all the figures on pp. 625 and 633, we note that temperature and crater wear indeed are related.

21.15 Is material ductility important for machinability? Explain.

Let's first note that the general definition of machinability (Section 21.7 on p. 638) involves workpiece surface finish and integrity, tool life, force and power required, and chip control. Ductility directly affects the type of chip produced which, in turn, affects surface finish, the nature of forces involved (less ductile materials may lead to tool chatter), and more ductile materials produce continues chips which may not be easy to control.

21.16 Explain why studying the types of chips produced is important in understanding cutting operations.

It is important to study the types of chips produced (see Section 21.2.1 on p. 613) because they significantly influence the surface finish produced, cutting forces, as well as the overall cutting operation. Note, for example, that continuous chips are generally associated with good surface finish and steady cutting forces. Built-up edge chips usually result in poor surface finish; serrated chips can have similar effects. Discontinuous chips usually result in poor surface finish and dimensional accuracy, and involve cutting forces that fluctuate. Thus, the type of chip is a good indicator of the overall quality of the cutting operation.

21.17 Why do you think the maximum temperature in orthogonal cutting is located at about the middle of the tool-chip interface? (Hint: Note that the two sources of heat are (a) shearing in the primary shear plane and (b) friction at 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 (see, for example, Fig. 21.12 on p. 625). The chip reaches high temperatures in the primary shear plane, and the temperature would decrease from then on. If no frictional heat was involved, we would expect the highest temperature to occur at the shear plane. After the chip is formed, it slides up the rake face of the tool. The friction at the tool-chip interface is a heat source and thus increases the temperature, and hence the temperature due only to frictional heating would be highest at the end of the tool-chip contact length. These two opposing effects are additive and, as a result, we find that the temperature is highest somewhere in between the tool tip and the end of the tool-chip contact zone.

21.18 Tool life can be almost infinite at low cutting speeds. Would you then recommend that all machining be done at low speeds? Explain.

Tool life can be almost infinite at very low cutting speeds (see Fig. 21.16 on p. 629) but this reason alone would not necessarily justify using low cutting speeds. Most obviously, low cutting speeds remove less material in a given time which, unless otherwise justified, would be economically undesirable. Lower cutting speeds also often also lead to the formation of a built-up edge and discontinuous chips, thus affecting surface finish. (See also Example 21.4 on p. 631.)

21.19 Explain the consequences of allowing temperatures to rise to high levels in cutting.

By the student. There are several consequences of allowing temperatures to rise to high levels in cutting (see also pp. 623-624), such as: (a) Tool wear will be accelerated due to high temperatures. (b) High temperatures will cause dimensional changes in the workpiece, thus reducing dimensional accuracy. (c) Excessively high temperatures in the cutting zone can induce thermal damage and metallurgical changes to the machined surface.

21.20 The cutting force increases with depth-of-cut and decreasing rake angle. Explain why.

It is logical that the cutting force increases as the depth of cut increases and rake angle decreases. Deeper cuts remove more material, thus requiring a higher cutting force. As the rake angle, α, decreases, the shear angle, ϕ , decreases (see Eqs. (21.3) and (21.4) on p. 612), and hence shear energy dissipation and cutting forces increase.

21.21 Why is it not always advisable to increase cutting speed in order to increase production rate?

The main consideration here is that as the cutting speed increases, tool life decreases. See also Example 21.4 on p. 631 and note that there has to be an optimum cutting speed, as also discussed in Section 25.8 on p. 783.

21.22 What are the consequences if a cutting tool chips?

By the student. Tool chipping has various effects, such as poor surface finish and dimensional control of the part being machined; possible temperature rise; and cutting force fluctuations and increases. Chipping is indicative of a harmful condition for the cutting tool material, and often is followed by more extreme failure.

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

By the student. There are many effects of performing a cutting operation with a dull tool. Note that a dull tool has an increased tip radius (see Fig. 21.22 on p. 636); as the tip radius increases (the tool dulls), the cutting force increases due to the fact that the effective rake angle is decreased. In addition, we can see that shallow depths of cut may not be possible because the tool may simply ride over the surface without producing chips. Another effect is inducing surface residual stresses, tearing, and cracking of the machined surface due to 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.

21.24 To what factors do you attribute the difference in the specific energies when machining the materials shown in Table 21.2? Why is there a range of energies for each group of material?

The differences in specific energies observed in Table 21.2 on p. 622, whether among different materials or within types of materials, can be attributed to differences in the mechanical and physical properties of these materials, which affect the cutting operation. For example, as the material strength increases, so does the total specific energy. Differences in frictional characteristics of the tool and workpiece materials would also play a role. Physical properties such as thermal conductivity and specific heat, both of which increase cutting temperatures as they decrease (see Eq. (21.19a) on p. 624), also could be responsible for such differences in practice. These points are confirmed when one closely examines Table 21.2 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 large variety of materials which fall under these categories.

21.25 Explain why it is possible to remove more material between tool resharpenings by lowering the cutting speed.

The main consideration here is that as the cutting speed increases, tool life decreases. See Example 21.4 on p. 631. As the example states, there is, of course, an optimum cutting speed, as also discussed in Section 25.8 on p. 783.

21.26 Noting that the dimension d in Fig. 21.4a is very small, explain why the shear strain rate in metal cutting is so high.

The shear strain rate in metal cutting is high even though the dimension d is very small. Referring to Fig. 21.4 on p. 611, we note that shear-strain rate is defined as the ratio of shear velocity, V_s, to the dimension d in the shear plane. Since V_s is on the same order of magnitude as the cutting speed, V, and the dimension d is very small (on the order of 10^{-2} to 10^{-3} in.), the shear strain rate is very high.

21.27 Explain the significance of Eq. (21.7).

The significance of Eq. (21.7) on p. 619 is that it determines an effective rake angle for oblique cutting (a process of more practical significance in most machining operations), which we can relate back to the simpler orthogonal cutting models for purposes of analysis. Oblique cutting is extremely complicated otherwise, and certainly cannot be treated effectively in an undergraduate textbook without Eq. (21.7).

21.28 Comment on your observations regarding Figs. 21.12 and 21.13.

By the student. General observations are as follows:

(a) The maximum temperature, both on flank and rake faces, are at a location approximately halfway along the tool-workpiece contact surfaces.

(b) Temperatures and their gradients can be very high.

(c) Cutting speed has a major effect on temperature.

(d) Chip temperatures are much higher than workpiece temperatures.

21.29 Describe the consequences of exceeding the allowable wear land (Table 21.4) for various cutting-tool materials.

The major consequences would be:

(a) As the wear land increases, the wear flat will rub against the machined surface and thus temperature will increase due to friction.

(b) Dimensional control will become difficult and surface damage may result.

(c) Some burnishing may also take place on the machined surface, leading to residual stresses and temperature rise.

(d) Cutting forces will increase because of the increased land, requiring greater power for the same machining operation.

21.30 Comment on your observations regarding the hardness variations shown in Fig. 21.6a.

By the student. What is obvious in Fig. 21.6a on p. 21.6a on p. 615 is that the chip undergoes a very high degree of strain hardening, as evidenced by the hardness distribution in the chip. Also, there is clearly and not surprisingly an even higher level of cold work in the built-up edge, to as much as three times the workpiece hardness.

21.31 Why does the temperature in cutting depend on the cutting speed, feed, and depth-of-cut? Explain in terms of the relevant process variables.

Refer to Eq. (21.19a) on p. 624. As cutting speed increases, there is less time for the heat generated to be dissipated, hence temperature increases. As feed increases (such as in turning; see Fig. 21.2 on p. 608) or as the depth of cut increases (such as in orthogonal cutting), the chip is thicker. With larger thickness-to-surface area of the chip, there is less opportunity for the heat to be dissipated, hence temperature increases.

21.32 You will note that the values of a and b in Eq. (21.19b) are higher for high-speed steels than for carbides. Why is this so?

As stated on p. 624, the magnitudes of a and b depend on the type of cutting tool as well as the workpiece materials. Factors to be considered include thermal conductivity and friction at the tool-chip and tool-workpiece interfaces. Carbides have higher thermal conductivity than high-speed steels (see Table 21.1 on p. 649) and also have lower friction. Consequently, these constants are lower for carbides; in other words, the temperature is less sensitive to speed and feed.

21.33 As shown in Fig. 21.14, the percentage of the total cutting energy carried away by the chip increases with cutting speed. Why?

The reason is due to the fact that as cutting speed increases, the heat generated (particularly that portion due to the shear plane deformation) is carried away at a higher rate. Conversely, if the speed is low, the heat generated will have more time to dissipate into the workpiece.

21.34 Describe in detail the effects that a dull tool can have on cutting operations.

By the student. There are many effects of performing a cutting operation with a dull tool. Note that a dull tool has an increased tip radius (see Fig. 21.22 on p. 636); as the tip radius increases (the tool dulls), the cutting force increases due to the fact that the effective rake angle is decreased. In addition, we can see that shallow depths of cut may not be possible because the tool may simply ride over the surface without producing chips. Another effect is inducing surface residual stresses, tearing, and cracking of the machined surface due to 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.

21.35 Explain whether it is desirable to have a high or low (a) n value and (b) C value in the Taylor tool-life equation.

As we can see in Fig. 21.17 on p. 629, high n values are desirable because, for the same tool life, we can cut at higher speeds, thus increasing productivity. Conversely, we can also see that for the same cutting speed, high n values give longer tool life. Note that as n approaches zero, tool life becomes extremely sensitive to cutting speed. These trends can also be seen by inspecting Eq. (21.20a) on p. 628. As for the value of C, note that its magnitude is the same as the cutting speed at $T = 1$. Consequently, it is desirable to have high C values because we can cut at higher speeds, as can also be seen in Fig. 21.17.

21.36 The tool-life curve for ceramic tools in Fig. 21.17 is to the right of those for other tool materials. Why?

Ceramic tools are harder and have higher resistance to temperature; consequently, they resist wear better than other tool materials shown in the figure. Ceramics are also chemically inert even at the elevated temperatures of machining. The high hardness leads to abrasive wear resistance, and the chemical inertness leads to adhesive wear resistance.

21.37 Why are tool temperatures low at low cutting speeds and high at high cutting speeds?

At very low cutting speeds, as energy is dissipated in the shear plane and at chip-tool interface, it is conducted through the workpiece and/or tool and eventually to the environment. At higher speeds, conduction cannot take place quickly enough to prevent temperatures from rising significantly. At even higher speeds, however, the heat will be taken away by the chip, hence the workpiece will stay cool. This is one of the major advantages of high speed machining (see Section 25.5 on p. 760).

21.38 Can high-speed machining be performed without the use of a cutting fluid?

Yes, this is precisely the emphasis of Case Study 25.1 on p. 779. The main purposes of a cutting fluid (see Section 21.12 on p. 665) is to lubricate and to remove heat, usually accomplished by flooding the tool and workpiece by the fluid. 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 (see also Fig. 21.14 on p. 626).

21.39 Given your understanding of the basic metal-cutting process, what are the important physical and chemical properties of a cutting tool?

Physically, the important properties are hardness (especially hot hardness), toughness, thermal conductivity and thermal expansion coefficient. Chemically, it must be inert to the workpiece material at the cutting temperatures.

QUANTITATIVE PROBLEMS

21.40 Let $n = 0.5$ and $C = 300$ in the Taylor equation for tool wear. What is the percent increase in tool life if the cutting speed is reduced by (a) 30% and (b) 50%?

The Taylor equation for tool wear is given by Eq. (21.20a) on p. 628, which can be rewritten as

$$C = VT^n$$

Thus, for the case of $C = 300$ and $n = 0.5$, we have $300 = V\sqrt{T}$.

(a) To determine the percent increase in tool life if the cutting speed is reduced by 30%, let $V_2 = 0.7V_1$. We may then write

$$0.7V_1\sqrt{T_2} = V_1\sqrt{T_1}$$

Rearranging this equation, we find that $T_2/T_1 = 2.04$, hence tool life increases by 104%.

(b) To determine the percent increase in tool life if the cutting speed is reduced by 50%, we follow the same procedure and find that $T_2/T_1 = 4$. This means that tool life increases by (4 - 1)/1 = 3, or 300%.

21.41 Assume that, in orthogonal cutting, the rake angle is 15° and the coefficient of friction is 0.2. Using Eq. (21.3), determine the percentage increase in chip thickness when the friction is doubled.

We begin with Eq. (21.1b) on p. 611 which shows the relationship between the chip thickness and depth of cut. Assuming that the depth of cut and the rake angle are constant, we can rewrite this equation as

$$\frac{t_o}{t_c} = \frac{\cos(\phi_2 - \alpha)\sin\phi_2}{\cos(\phi_1 - \alpha)\sin\phi_2}$$

Now, using Eq. (21.3) on p. 612 we can determine the two shear angles. For Case 1, we have from Eq. (21.4) that $\mu = 0.2 = \tan\beta$, or $\beta = 11.3^\circ$, and hence

$$\phi_2 = 45^\circ + \frac{15^\circ}{2} - \frac{11.3^\circ}{2} = 46.85^\circ$$

and for Case 2, where $\mu = 0.4$, we have $\beta = \tan^{-1} 0.4 = 21.8^\circ$ and hence $\phi_2 = 41.6^\circ$. Substituting these values in the above equation for chip thickness ratio, we obtain

$$\frac{t_o}{t_c} = \frac{\cos(\phi_2 - \alpha)\sin\phi_1}{\cos(\phi_1 - \alpha)\sin\phi_2} = \frac{\cos(41.6^\circ - 15^\circ)\sin 46.85^\circ}{\cos(46.85^\circ - 15^\circ)\sin 41.6^\circ} = 1.16$$

Therefore, the chip thickness increased by 16%.

21.42 Derive Eq. (21.11).

From the force diagram shown in Fig. 21.11 on p. 620, we express the following:

$$F = (F_t + F_c\tan\alpha)\cos\alpha$$

and

$$N = (F_c - F_t\tan\alpha)\cos\alpha$$

Therefore, by definition,

$$\mu = \frac{F}{N} = \frac{(F_t + F_c\tan\alpha)\cos\alpha}{(F_c - F_t\tan\alpha)\cos\alpha}$$

21.43 Taking carbide as an example and using Eq. (21.19b), determine how much the feed should be reduced in order to keep the mean temperature constant when the cutting speed is tripled.

We begin with Eq. (21.19b) on p. 624 which, for our case, can be rewritten as

$$V_1^a f_1^b = (3V_1)^a f_2^b$$

Rearranging and simplifying this equation, we obtain

$$\frac{f_2}{f_1} = 3^{-a/b}$$

For carbide tools, approximate values are given on p. 624 as $a = 0.2$ and $b = 0.125$. Substituting these, we obtain

$$\frac{f_2}{f_1} = 3^{-(0.2/0.125)} = 0.17$$

Therefore, the feed should be reduced by (1-0.17) = 0.83, or 83%.

21.44 Using trigonometric relationships, derive an expression for the ratio of shear energy to frictional energy in orthogonal cutting, in terms of angles α, β, and ϕ only.

We begin with the following expressions for u_s and u_f, respectively (see p. 622):

$$u_s = \frac{F_s V_s}{w t_o V} \quad \text{and} \quad u_f = \frac{F V_c}{w t_o V}$$

Thus their ratio becomes

$$\frac{u_s}{u_f} = \frac{F_s V_s}{F V_c}$$

The terms involved above can be defined as

$$F = R \sin\beta$$

and from Fig. 21.11 on p. 620,

$$F_s = R\cos(\phi + \beta - \alpha)$$

However, we can simplify this expression further by noting in the table for Problem 20.48 below that the magnitudes of ϕ and α are close to each other. Hence we can approximate this expression as

$$F_s = R\cos\beta$$

Also,

$$V_s = \frac{V\cos\alpha}{\cos(\phi - \alpha)}$$

$$V_c = \frac{V\sin\alpha}{\cos(\phi - \alpha)}$$

Combining these expressions and simplifying, we obtain

$$\frac{u_s}{u_f} = \cot\beta\cot\alpha$$

21.45 An orthogonal cutting operation is being carried out under the following conditions: $t_o = 0.1$ mm, $t_c = 0.2$ mm, width of cut = 5 mm, $V = 2$ m/s, rake angle = $10°$, $F_c = 500$ N, and $F_t = 200$ N. Calculate the percentage of the total energy that is dissipated in the shear plane.

The total power dissipated is obtained from Eq. (21.13) on p. 621 and the power for shearing from Eq. (21.14). Thus, the total power is

$$\text{Power} = (500)(2) = 1000\text{N-m/s}$$

To determine power for shearing we need to determine F_s and V_s. We know that

$$F_s = R\cos(\phi + \beta - \alpha)$$

where

$$R = \sqrt{(500)^2 + (200)^2} = 538 \text{ N}$$

also, ϕ is obtained from Eq. (20.1) where $r = 0.1/0.2 = 0.5$. Hence

$$\phi = \tan^{-1}\left[\frac{(0.5)(\cos 10^\circ)}{1-(0.5)(\sin 10^\circ)}\right] = 28.4^\circ$$

We can then determine β from the expression

$$F_c = R\cos(\beta - \alpha)$$

or,

$$500 = 538\cos(\beta - 10^\circ)$$

Hence

$$\beta = 31.7^\circ$$

Therefore,

$$F_s = 538\cos(28.4^\circ + 31.7^\circ - 10^\circ) = 345 \text{ N}$$

which allows us to calculate V_s using Eq. (21.6a) on p. 613. Hence,

$$V_s = 2\cos 10^\circ / \cos(28.4^\circ - 10^\circ) = 2.08 \text{ m/s}$$

and the power for shearing is (345)(2.08) = 718 N-m/s. Thus, the percentage is 718/1000 = 0.718, or about 72%.

21.46 Explain how you would go about estimating the C and n values for the four tool materials shown in Fig. 21.17.

From Eq. (21.20) on p. 628 we note that the value of C corresponds to the cutting speed for a tool life of 1 min. From Fig. 21.16 on p. 629 and by extrapolating the tool-life curves to a tool life of 1 min. we estimate the C values approximately as (ranging from ceramic to HSS) 11000, 3000, 400, and 200, respectively. Likewise, the n values are obtained from the negative inverse slopes, and are estimated as: 0.73 (36°), 0.47 (25°), 0.14 (8°), and 0.11 (6°), respectively. Note that these n values compare well with those given in Table 21.3 on p. 628.

21.47 Derive Eq. (21.1).

Refer to the shear-plane length as l. Figure 21.3 on p. 609 suggests that the depth of cut, t_o, is given by

$$t_o = l\sin\phi$$

Similarly, from Fig. 21.4 on p. 611, the chip thickness is seen to be

$$t_c = l\cos(\phi - \alpha)$$

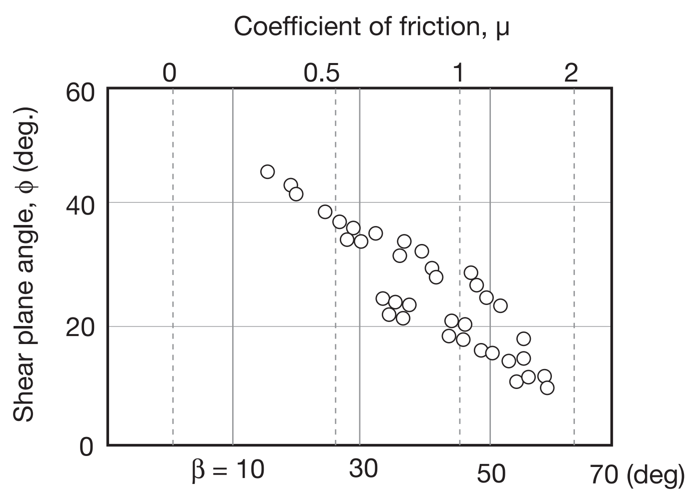
Substituting these relationships into the definition of cutting ratio gives

$$r = \frac{t_o}{t_c} = \frac{l\sin\phi}{l\cos(\phi-\alpha)} = \frac{\sin\phi}{\cos(\phi-\alpha)}$$

21.48 Assume that, in orthogonal cutting, the rake angle, α, is 25° and the friction angle, β, is 30° at the chiptool interface. Determine the percentage change in chip thickness when the friction angle is 50°. (Note: Do not use Eq. (21.3) or (21.4).

This problem is similar to Problem 20.41 above. However, since it states that we cannot use Eq. (21.3) on p. 612, we have to find a means to determine the shear angle, ϕ, first. This requires further reading by the student to find other shear-angle relationships similar to Eq. (21.3) or Eq. (21.4), with the guidance of the instructor and referring to the Bibliography at the end of this chapter. Note that many researchers have measured shear plane angles and developed shear plane angle relationships; this solution is only one example of an acceptable answer, and students should be encouraged to find a solution based on their own literature review. Indeed, such a literature review is an invaluable exercise.

This solution will use experimental measurements of the shear plane angle obtained by S. Kobayashi and printed in Kalpakjian, S., *Manufacturing Processes for Engineering Materials*, 3rd ed., 1997:



From this chart, we can estimate that for $\beta = 30^\circ$, ϕ is approximately 25° and if $\beta = 50^{c}irc$, $\phi = 15^\circ$. We now follow the same approach as in Problem 20.41. We begin with Eq. (21.1) on p. 600 which shows the relationship between the chip thickness and depth of cut. Assume that the depth of cut and the rake angle are constant, we can rewrite this equation as

$$\frac{t_o}{t_c} = \frac{\cos(\phi_2 - \alpha)\sin\phi_1}{\cos(\phi_1 - \alpha)\sin\phi_2} = \frac{\cos(15^\circ - 25^\circ)\sin 25^\circ}{\cos(25^\circ - 25^\circ)\sin 15^\circ} = 1.60$$

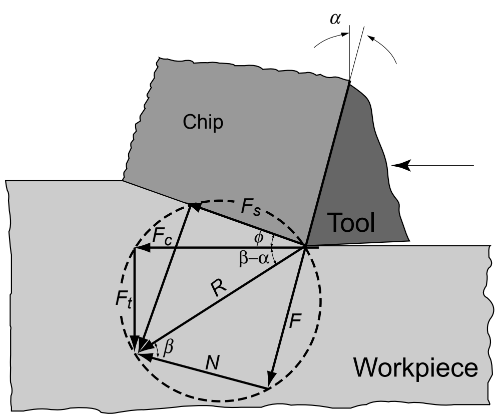
Therefore, the chip thickness increased by 60 percent.

21.49 Show that, for the same shear angle, there are two rake angles that give the same cutting ratio.

By studying Eq. (21.1b) on p. 611, we note that the denominator can give the same value for the angle $(\phi - \alpha)$ that is either positive or negative. Therefore, the statement is correct.

21.50 With appropriate diagrams, show how the use of a cutting fluid can change the magnitude of the thrust force, F_t , in Fig. 21.11.

Note in Fig. 21.11 on p. 620 that the use of a cutting fluid will reduce the friction force, F, at the tool-chip interface. This, in turn, will change the force diagram, hence the magnitude of the thrust force, F_t. Consider the sketch given below. The left sketch shows cutting without an effective cutting fluid, so that the friction force, F is large compared to the normal force, N. The sketch on the right shows the effect if the friction force is a smaller fraction of the normal force because of this cutting fluid. As can be seen, the cutting force is reduced with the effective fluid. The largest effect is on the thrust force, but there is a noticeable effect on cutting force. This effect becomes larger as the rake angle increases.



21.51 For a turning operation using a ceramic cutting tool, if the speed is increased by 50%, by what factor must the feed rate be modified to obtain a constant tool life? Use $n = 0.5$ and $y = 0.6$.

Equation (21.22) on p. 628 will be used for this problem. Since the tool life is constant, we can write the following:

$$C^{1/n} V_1^{-1/n} d_1^{-x/n} f_1^{-y/n} = C^{1/n} V_2^{-1/n} d_2^{-x/n} f_2^{-y/n}$$

Note that the depth of cut is constant, hence $d_1 = d_2$, and also it is given that $V_2 = 1.5V_1$. Substituting the known values into this equation yields:

$$V_1^{-2} f_1^{-0.6/0.5} = (1.5V_1)^{-2} f_2^{-0.6/0.5}$$

or

$$1.5^2 = \left(\frac{f_2}{f_1}\right)^{-1.2}$$

so that

$$\frac{f_2}{f_1} = \left(1.5^2\right)^{1/1.2} = 50.8$$

21.52 In Example 21.3, if the cutting speed, V, is doubled, will the answer be different? Explain.

Refer to Example 21.3 on p. 630. The values of $n = 0.5$ and $C = 400$ are preserved, and the values of $V_2 = 2V_1$ will be used. The Taylor tool life equation can be written as

$$2V_1\sqrt{T_2} = V_1\sqrt{T_1}$$

Simplifying this expression,

$$\frac{\sqrt{T_2}}{\sqrt{T_1}} = \frac{V_1}{2V_1} = \frac{1}{2} \quad \rightarrow \quad \frac{T_2}{T_1} = 0.25$$

Therefore, the life has been reduced by 75%.

21.53 Using Eq. (21.24) select an appropriate feed for $R = 1$ mm and a desired roughness of 1 μm. How would you adjust this feed to allow for nose wear of the tool during extended cuts? Explain your reasoning.

If $R_a = 1$ μm, and $R = 1$ mm, then

$$f^2 = (1\ \mu\text{m})(8)(1\ \text{mm}) = 8 \times 10^{-9}\ \text{m}^2 \quad \rightarrow \quad f = 0.089\ \text{mm/rev}$$

If nose wear occurs, then the radius will increase. The feed will similarly have to increase, per the equation above.

21.54 Using a carbide cutting tool, the temperature in a cutting operation with a speed of 300 ft/min and feed of 0.002 in./rev is measured to be 1200°F. What is the approximate temperature if the speed is doubled? What speed is required to lower the maximum cutting temperature to 900°F?

Equation (21.19a) on p. 624 is needed to solve this problem, which is rewritten as:

$$T_{\text{mean}} = \frac{1.2Y_f}{\rho c}\sqrt[3]{\frac{Vt_o}{K}} \quad \rightarrow \quad \frac{T_{\text{mean}}}{\sqrt[3]{V}} = \frac{1.2Y_f}{\rho c}\sqrt[3]{\frac{t_o}{K}}$$

Note that the text warns that appropriate units need to be used. It is reasonable in this case to use °F instead of °R, because, clearly, a cutting speed near zero does not lead to temperatures below room temperature. Therefore, using $T_{\text{mean}} = 1200°\text{F}$ and $V = 300$ ft/min yields

$$\frac{T_{\text{mean}}}{\sqrt[3]{V}} = \frac{1.2Y_f}{\rho c}\sqrt[3]{\frac{t_o}{K}} = \frac{1200°\text{F}}{\sqrt[3]{300\ \text{ft/min}}}$$

For the first part of the problem, we take $V = 600$ ft/min, yielding

$$\frac{T_{\text{mean}}}{\sqrt[3]{600}} = \frac{1200°\text{F}}{\sqrt[3]{300\ \text{ft/min}}}$$

or $T_{\text{mean}} = 1511°\text{F}$. If the maximum temperature is lowered to 900°F, then we have

$$\frac{900°\text{F}}{\sqrt[3]{V}} = \frac{1200°\text{F}}{\sqrt[3]{300\ \text{ft/min}}}$$

which is solved as $V = 126$ ft/min.

21.55 Assume that you are an instructor covering the topics described in this chapter, and you are giving a quiz on the numerical aspects to test the understanding of the students. Prepare two quantitative problems and supply the answers.

By the student. This open-ended question requires considerable focus and understanding on the part of students, and has been found to be a very valuable homework problem.

SYNTHESIS, DESIGN, AND PROJECTS

21.56 As we have seen, chips carry away the majority of the heat generated during machining. If chips did not have this capacity, what suggestions would you make in order to be able to carry out machining processes without excessive heat? Explain.

By the student. If chips couldn't carry away the heat, then some other means would be needed to cool the workpiece and the cutting tool. The obvious solution is a generous flood of cutting fluid or more advanced methods such as high-pressure systems or through the cutting tool system, as described on p. 668.

21.57 Tool life is increased greatly when an effective means of cooling and lubrication is implemented. Design methods of delivering this fluid to cutting zone and discuss the advantages and limitations of your design.

By the student. See pp. 667-668.

21.58 Design an experimental setup whereby orthogonal cutting can be simulated in a turning operation on a lathe.

By the student. This can be done simply by placing a thin-walled tube in the headstock of a lathe (see Fig. 21.2 on p. 608, where the solid bar is now replaced with a tube) and machining the end of the tube with a simple, straight tool. The feed on the lathe will become the depth of cut, to, in orthogonal cutting, and the chip width will be the same as the wall thickness of the tube.

21.59 Describe your thought on whether chips produced during machining can be used to make useful products. Give some examples of possible products and comment on their characteristics and differences if the same products were made by other manufacturing processes. Which types of chips would be desirable for this purpose?

By the student. This can be a challenging problem and many students may conclude (incorrectly) that there are no useful products that can be made from chips. However, the following are some examples:

- Short or discontinuous chips, as well as thin and long chips, can be used as metal reinforcing fibers for nonmetallic materials such as polymers or cement.

- Shaved sheet can be produced from metal, as described in Problem 21.62.
- Metal filters can be produced by compacting the chips into solid shapes, as can be done using powder-metallurgy techniques.
- Novel jewelry can be produced from chips.

21.60 We have stated that cutting tools can be designed so that the tool-chip contact length is reduced by recessing the rake face of the tool some distance away from its tip. Explain the possible advantages of such a tool.

By the student. The principal reason is that by reducing the tool-chip contact, the friction force, F, is reduced, thus cutting forces are reduced. Chip morphology may also change. The student is encouraged to search the technical literature regarding this question.

21.61 We have stated the chip formation mechanism can also be observed by scraping the surface of a stick of butter with a sharp knife. Using butter at different temperatures, including frozen, conduct such an experiment. Keep the depth of cut constant and hold the knife at different angles (to simulate the tool rake angle), including oblique scraping. Describe your observations regarding the type of chips produced. Also comment on the force that your hand feels while scraping and whether you observe any chatter when the butter is very cold.

By the student. This is a simple experiment to perform. By changing the temperature of the stick of butter and the knife angle, one can demonstrate various chip formations and observe the changes that occur when the temperature is changed. Chattering of the knife and how it is related to chip morphology can also be explored.

21.62 Experiments have shown that it is possible to produce thin, wide chips, such as 0.08 mm (0.003 in.) thick and 10 mm (4 in.) wide, which would be similar to rolled sheet. Materials have been aluminum, magnesium, and stainless steel. A typical setup would be similar to orthogonal cutting, by machining the periphery of a solid round bar with a straight tool moving radially inward. Describe your thoughts on producing thin metal sheet by this method, its surface characteristics, and its properties.

By the student. There are some advantages to this material. The material has undergone an intense shear during cutting, and therefore the material develops a fine grained, highly oriented structure. One side (that against the tool) will have a shiny surface finish, while the other side is rough (see chip surfaces in Fig. 21.3a on p. 609 and Fig. 21.5 on p. 614).

21.63 Describe your thoughts on recycling of chips produced during machining in a plant. Include considerations regarding chips produced by dry cutting versus those produced by machining with a cutting fluid.

By the student. Chips are now recycled more commonly, although cutting-fluid reclamation (removal) is often attempted before melting the chips. Cutting fluids often can cause volatile organic compounds (to be exhausted upon combustion) so this can be an environmental issue. Also, an effort must to be made to keep classes of materials separate; for example, aluminum and steel chips have to be separated for recycling.