22 CUTTING TOOL TECHNOLOGY

Review Questions

22.1 What are the two principal aspects of cutting-tool technology?

Answer. The two principal aspects of cutting tool technology are (1) tool material and (2) tool geometry.

22.2 Name the three modes of tool failure in machining.

Answer. The three tool failure modes are (1) fracture failure, (2) temperature failure, and (3) gradual wear.

22.3 What are the two principal locations on a cutting tool where tool wear occurs?

Answer. Wear occurs on the top face of the cutting tool as crater wear and on the side or flank of the tool, called flank wear.

22.4 Identify the mechanisms by which cutting tools wear during machining.

Answer. The important tool wear mechanisms are (1) abrasion, (2) adhesion, (3) diffusion, (4) chemical reactions, and (5) plastic deformation of the cutting edge.

22.5 What is the physical interpretation of the parameter n in the Taylor tool life equation?

Answer. The parameter n is the slope of the log-log plot of the tool life data. It indicates how strongly tool life is affected by cutting speed.

22.6 What is the physical interpretation of the parameter C in the Taylor tool life equation?

Answer. The parameter C is the cutting speed corresponding to a one-minute tool life. C is the speed-axis intercept on the log-log plot of the tool life data.

22.7 What are some of the tool life criteria used in production machining operations?

Answer. As identified in the text, tool life criteria used in production include (1) complete failure of the tool, (2) visual observation of flank or crater wear by the machine operator, (3) changes in the sound emitted by the tool, (4) degradation of surface finish, (5) power increase, (6) workpiece count, and (7) length of cutting time for the tool.

22.8 Identify three desirable properties of a cutting-tool material.

Answer. Three desirable properties are (1) toughness to resist fracture failure, (2) hot hardness to resist temperature failure, and (3) wear resistance to prolong the life of the tool during gradual wear.

22.9 What are the principal alloying ingredients in high-speed steel?

Answer. Principal alloying ingredients in HSS are (1) either tungsten or a combination of tungsten and molybdenum, (2) chromium, (3) vanadium, and (4) carbon. Some grades of HSS also contain cobalt.

22.10 What is the difference in ingredients between steel cutting grades and nonsteel-cutting grades of cemented carbides?

Answer. In general, non-steel cutting grades contain only WC and Co. Steel cutting grades contain TiC and/or TaC in addition to WC-Co.

22.11 What is the difference between cemented carbides and cermets used as cutting tools in machining?

Answer. The term *cermet* in cutting tool technology refers to ceramic-and binder combinations other than WC-Co and WC-TiC-TaC-Co, which are known as *cemented carbides*, although technically, cemented carbides satisfy the general definition of a cermet.

22.12 Identify some of the common compounds that form the thin coatings on the surface of coated carbide inserts.

Answer. The common coatings are: TiN, TiC, and Al_2O_3.

22.13 What is the chemical formula of the ceramic material used in almost all ceramic cutting tools?

Answer. The chemical formula is Al_2O_3 for aluminum oxide.

22.14 Why can diamond cutting tools not be used to machine steel and other ferrous metals?

Answer. Machining steel and other ferrous metals with SPD tools is not practical because of the chemical affinity that exists between these metals and carbon, because diamond is carbon.

22.15 Name the seven elements of tool geometry for a single-point cutting tool.

Answer. The seven elements of single-point tool geometry are (1) back rake angle, (2) side rake angle, (3) end relief angle, (4) side relief angle, (5) end cutting edge angle, (6) side cutting edge angle, and (7) nose radius.

22.16 Why are ceramic cutting tools generally designed with negative rake angles?

Answer. Ceramics possess low shear and tensile strength but good compressive strength. During cutting, this combination of properties is best exploited by giving the tool a negative rake angle to load the tool in compression.

22.17 Identify the three alternative ways of holding and presenting a cutting edge for a single-point cutting tool during machining.

Answer. There are three principal ways: (1) solid shank, in which the cutting edge is an integral part of the tool shank, an example being high speed steel tooling; (2) brazed inserts, used for some cemented carbides; and (3) mechanically clamped inserts, used for most hard tool materials including cemented carbides, coated carbides, cermets, ceramics, SPD, and CBN.

22.18 Name the two main categories of cutting fluid according to function.

Answer. The two functional categories of cutting fluids are: (1) coolants and (2) lubricants.

22.19 Name the four categories of cutting fluid according to chemistry.

Answer. The four categories of cutting fluids according to chemistry are (1) cutting oils, (2) emulsified oils, (3) chemical fluids, and (4) semi-chemical fluids.

22.20 What are the principal lubricating mechanisms by which cutting fluids work?

Answer. There are two lubricating mechanisms that are believed to be effective in metal cutting: (1) boundary lubrication, which involves the formation of a thin fluid film to help separate and protect the contacting surfaces; and (2) extreme pressure lubrication, in which a thin solid layer of a salt such as iron sulfide is formed on the tool surface to provide lubrication.

22.21 What are the methods by which cutting fluids are applied in a machining operation?

Answer. The most common method of application is flooding, in which a steady stream of fluid is direct at the operation. Other methods include mist application, fluid-hole delivery through the tool, and manual application (e.g., using a paint brush).

22.22 Why are cutting fluid filter systems becoming more common, and what are their advantages?

Answer. Cutting fluid filter systems are becoming more common due to the environmental concerns and the need to prolong the life of the fluid before disposal. Advantages of filter systems include longer fluid life, reduced disposal costs, better hygiene, lower machine tool maintenance, and longer cutting tool life.

22.23 Dry machining is being considered by machine shops because of certain problems inherent in the use of cutting fluids. What are those problems associated with the use of cutting fluids?

Answer. Cutting fluids become contaminated over time with a variety of contaminants, including tramp oil, garbage, small chips, molds, fungi, and bacteria. In addition to causing odors and health hazards, contaminated cutting fluids do not perform their lubricating function as well as when they are fresh and clean.

22.24 What are some of the new problems introduced by machining dry?

Answer. Problems with dry machining include (1) overheating the tool, (2) operating at lower cutting speeds and production rates to prolong tool life, and (3) absence of chip removal benefits that are provided by cutting fluids in grinding and milling.

Problems

Answers to problems labeled **(A)** are listed in an Appendix at the back of the book.

Tool Life and the Taylor Equation

22.1 (SI units) In the tool wear plots of Figure 22.4, complete failure of the cutting tool is indicated by the end of each wear curve. Using complete failure as the criterion of tool life instead of 0.50-mm flank wear, the resulting data are: (1) v = 160 m/min, T = 5.75 min; (2) v = 130 m/min, T = 14.25 min; and (3) v = 100 m/min, T = 47 min. Determine the parameters n and C in the Taylor tool life equation for this data.

Solution: Use the two extreme data points to calculate the values of n and C, then check the resulting equation against the middle data point.

(1) $160(5.75)^n = C$ and (3) $100(47)^n = C$

$160(5.75)^n = 100(47)^n$

$\ln 160 + n \ln 5.75 = \ln 100 + n \ln 47$

$5.0752 + 1.7492\,n = 4.6052 + 3.8501\,n$

$0.4700 = 2.1009\,n$ **n = 0.224**

(1) $C = 160(5.75)^{0.224} = 236.7$

(3) $C = 100(47)^{0.224} = 236.9$ use average: **C = 236.8 m/min**

Check against data set (2): $130(14.25)^{0.224} = 235.7$. This represents a difference of less than 0.5%, which would be considered good agreement for experimental data. Better results on determining the Taylor equation would be obtained by using regression analysis on all three data sets to smooth the variations in the tool life data. Note that the n value is very close to the value obtained in Example 22.1 ($n = 0.224$ here vs. $n = 0.223$ in Example 22.1), and that the C value is higher here ($C = 236.8$ here vs. $C = 229$ in Example 22.1). The higher C value here reflects the higher wear level used to define tool life (complete failure of cutting edge here vs. a flank wear level of 0.50 mm in Example 22.1).

22.2 **(A)** (SI units) In turning tests using coated carbide tools on alloy steel, flank wear data were collected at a feed of 0.30 mm/rev and a depth of 3.0 mm. At a speed of 125 m/min, flank wear = 0.12 mm at 1 min, 0.27 mm at 5 min, 0.45 mm at 11 min, 0.58 mm at 15 min, 0.73 at 20 min, and 0.97 mm at 25 min. At a speed of 165 m/min, flank wear = 0.22 mm at 1 min, 0.47 mm at 5 min, 0.70 mm at 9 min, 0.80 mm at 11 min, and 0.99 mm at 13 min. The last value in each case is when final tool failure occurred. (a) On a single piece of linear graph paper, plot flank wear as a function of time for both speeds. Using 0.75 mm of flank wear as the criterion of tool failure, determine the tool lives for the two cutting speeds. (b) On a piece of natural log-log paper, plot your results from part (a) to determine the values of n and C in the Taylor tool life equation. (c) As a comparison, calculate the values of n and C in the Taylor equation solving simultaneous equations. Are the resulting n and C values the same?

Solution: (a) and (b) Student exercises. For part (a), at $v_1 = 125$ m/min, $T_1 = 20.4$ min using criterion $FW = 0.75$ mm, and at $v_2 = 165$ m/min, $T_2 = 10.0$ min using criterion $FW = 0.75$ mm. In part (b), values of C and n may vary due to variations in the plots. The values should be approximately the same as those obtained in part (c) below.

(c) Two equations: (1) $125(20.4)^n = C$, and (2) $165(10.0)^n = C$
(1) and (2) $125(20.4)^n = 165(10.0)^n$
$\ln 125 + n \ln 20.4 = \ln 165 + n \ln 10.0$
$4.8283 + 3.0155\, n = 5.1059 + 2.3026\, n$
$0.7129\, n = 0.2776$ **n = 0.3894**
(1) $C = 125(20.4)^{0.3894} = 404.46$
(2) $C = 165(10.0)^{0.3894} = 404.46$ **C = 404.46 m/min**

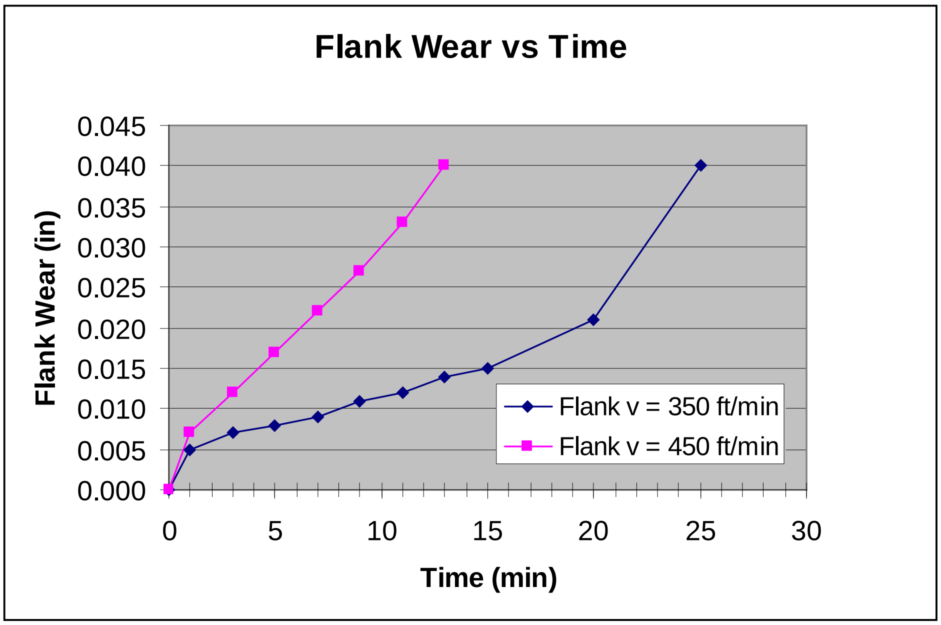
22.3 (SI units) Solve the previous problem except that the tool life criterion is 0.50 mm of flank land wear rather than 0.75 mm.

Solution: (a) and (b) Student exercises. For part (a), at $v_1 = 125$ m/min, $T_1 = 13.0$ min using criterion $FW = 0.50$ mm, and at $v_2 = 165$ m/min, $T_2 = 5.6$ min using criterion $FW = 0.50$ mm. In part (b), values of C and n may vary due to variations in the plots. The values should be approximately the same as those obtained in part (c) below.

(c) Two equations: (1) $125(13.0)^n = C$, and (2) $165(5.6)^n = C$
(1) and (2) $125(13.0)^n = 165(5.6)^n$
$\ln 125 + n \ln 13.0 = \ln 165 + n \ln 5.6$
$4.8283 + 2.5649\, n = 5.1059 + 1.7228\, n$
$0.8421\, n = 0.2776$ **n = 0.3296**
(1) $C = 125(13.0)^{0.3894} = 291.14$
(2) $C = 165(5.6)^{0.3894} = 291.15$ **C = 291.15 m/min**

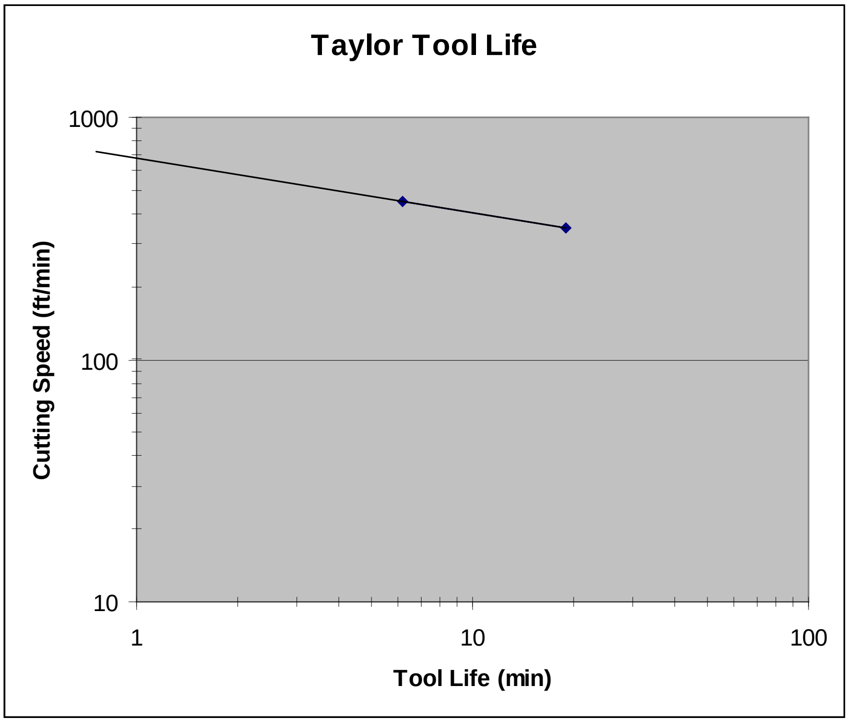
22.4 (USCS units) A series of turning tests using cemented carbide tools on medium carbon steel were conducted to collect flank wear data. Feed = 0.010 in/rev and = depth of cut = 0.125 in. At a speed of 350 ft/min, flank wear = 0.005 in at 1 min, 0.008 in at 5 min, 0.012 in at 11 min, 0.015 in at 15 min, 0.021 in at 20 min, and 0.040 in at 25 min. At a speed of 450 ft/min, flank wear = 0.007 in at 1 min, 0.017 in at 5 min, 0.027 in at 9 min, 0.033 in at 11 min, and 0.040 in at 13 min. The last value in each case is when final tool failure occurred. (a) On a single piece of linear graph paper, plot flank wear as a function of time. Using 0.020 in of flank wear as the criterion of tool failure, determine the tool lives for the two cutting speeds. (b) On a piece of natural log-log paper, plot your results from part (a) to determine the values of *n* and *C* in the Taylor tool life equation. (c) As a comparison, calculate the values of *n* and *C* in the Taylor equation solving simultaneous equations. Are the resulting *n* and *C* values the same?

Solution: (a)



Using the graph, at 350 ft/min the tool last about **6.2 min**; at 450 ft/min, it lasts **19.0 min**.

(b) The points are graphed in Excel and the line connecting the two points is extended to the axis.



C is read from the y-intercept and is approximately 680 ft/min. The slope, n, can be determined by taking the natural logs of the x and y coordinates of any 2 points and determining $\Delta y/\Delta x$. It is positive because the Taylor tool life equation is derived assuming the slope is negative. Using the points (1680) and (19,350) the slope is about 0.226.

(c) Depending on the values of tool life read from the flank wear graph, the values of n and C will vary. Two equations: (1) $350(19.0)^n = C$, and (2) $450(6.2)^n = C$
(1) and (2) $350(19.0)^n = 450(6.2)^n$
$\ln 350 + n \ln 19.0 = \ln 450 + n \ln 6.2$
$5.8579 + 2.9444\, n = 6.1092 + 1.8245\, n$
$1.1199\, n = 0.2513$ **n = 0.224**
(1) $C = 350(19.0)^{0.224} = 677$
(2) $C = 450(6.2)^{0.224} = 677$ **C = 677 ft/min**

22.5 (USCS units) Solve the previous problem except the tool life wear criterion is 0.015 in of flank wear. What cutting speed should be used to get 20 min of tool life?

Solution: Reading the time of tool failure on the Flank Wear vs Time plot yields the following data points. Note the values of n and C will change based on the estimates for time of failure. v_1 = 350 ft/min, T_1 = 15 min and v_2 = 450 ft/min, T_2 = 4.2 min

Two equations: (1) $350(15.0)^n = C$, and (2) $450(4.2)^n = C$
(1) and (2) $350(15.0)^n = 450(4.2)^n$
$\ln 350 + n \ln 15.0 = \ln 450 + n \ln 4.2$
$5.8579 + 2.7081\, n = 6.1092 + 1.4351\, n$
$1.2730\, n = 0.2513$ **n = 0.197**
(1) $C = 350(15.0)^{0.197} = 597$
(2) $C = 450(4.2)^{0.197} = 597$ **C = 597 ft/min**

To achieve 20 min of tool life: $v = C/T^n = 597/20^{0.197} = 597/1.8065 =$ **330 ft/min**

22.6 (SI units) Turning tests using cemented carbide tooling resulted in a 1-min tool life at a cutting speed = 4.8 m/s and a 25-min tool life at a speed = 2.0 m/s. (a) Find the *n* and *C* values in the Taylor tool life equation. (b) Project how long the tool would last at a speed of 1.0 m/s.

Solution: (a) For data (1) $T = 1.0$ min, then $\boldsymbol{C}$ **= 4.8 m/s = 288 m/min**
For data (2) $v = 2$ m/s = 120 m/min
$120(25)^n = 288$
$25^n = 288/120 = 2.4$
$n \ln 25 = \ln 2.4$
$3.2189\, n = 0.8755$ $\qquad$ $\boldsymbol{n = 0.272}$
The tool life equation is $vT^{0.272} = 288$

(b) At $v = 1.0$ m/s = 60 m/min
$60(T)^{0.272} = 288$
$(T)^{0.272} = 288/60 = 4.8$
$T = (4.8)^{1/0.272} = (4.8)^{3.677} =$ **320 min**

22.7 **(A)** (SI units) The following data were collected during tool life tests in turning: (1) when $v = 100$ m/min, $T = 9$ min; (2) when $v = 75$ m/min, $T = 35$ min. (a) Determine the *n* and *C* values in the Taylor tool life equation. Based on your equation, compute the (b) tool life for a speed of 110 m/min and (c) speed for a tool life of 20 min.

Solution: (a) Two equations: (1) $100(9)^n = C$ and (2) $75(35)^n = C$
$100(9)^n = 75(35)^n$
$\ln 100 + n \ln 9 = \ln 75 + n \ln 35$
$4.6052 + 2.1972\, n = 4.3175 + 3.5553\, n$
$4.6052 – 4.3175 = (3.5553 – 2.1972)\, n$
$0.2877 = 1.3581\, n$ $\qquad$ $\boldsymbol{n = 0.212}$
$C = 100(9)^{0.2925} = 100(1.5933)$ $\qquad$ $\boldsymbol{C}$ **= 159.3 m/min**
Check: $C = 75(35)^{0.212} = 75(2.1249) = 159.4$
Use $C = 159$. The tool life equation is $vT^{0.212} = 159$

(b) $110\, T^{0.212} = 159$
$T^{0.212} = 159/110 = 1.445$
$T = 1.445^{1/0.212} = 1.445^{4.717} =$ **5.7 min**

(c) $v(20)^{0.212} = 159$
$v = 159/(20)^{0.212} = 159/1.887 =$ **84 m/min**

22.8 (USCS units) Tool life tests in turning yielded the following data: (1) at $v = 350$ ft/min, T =5.2 min; (2) at $v = 250$ ft/min, $T = 55$ min. (a) Determine the parameters *n* and *C* in the Taylor tool life equation. (b) Based on these values, what is the likely tool material used in this operation? (c) Using your equation, compute the tool life for a cutting speed of 300 ft/min. (d) Compute the cutting speed for a tool life = 10 min.

Solution: (a) Two equations for $vT^n = C$: (1) $350(5.2)^n = C$ and (2) $250(55)^n = C$
$350(5.2)^n = 250(55)^n$
$350/250 = (55/5.2)^n$

$1.40 = (10.577)^n$
$\ln 1.40 = n \ln 10.577$
$0.3365 = 2.359\, n$ **$n = 0.143$**
$C = 350(5.2)^{0.143} = 350(1.2652)$ **$C = 442.8$**
Check: $C = 250(55)^{0.143} = 250(1.771) = 442.8$
Use $C = 443$. The tool life equation is $vT^{0.143} = 443$ ft/min

(b) Comparing these values of n and C with those in Table 22.2, the likely tool material is high speed steel.

(c) At $v = 300$ ft/min, $T = (C/v)^{1/n} = (443/300)^{1/0.143} = (1.477)^{7.009} =$ **15.4 min**

(d) For $T = 10$ min, $v = C/T^n = 443/10^{0.143} = 443/1.389 =$ **319 ft/min**

22.9 **(A)** (USCS units) A 22-in-long by 3.0-in-wide cast iron rectangular block is machined in a face milling operation using a 6.0-in-diameter cutter with 12 carbide inserts. The cutter path is centered over the width of the block. Feed = 0.008 in/tooth and depth of cut = 0.60 in. At a cutting speed of 500 ft/min, the tool lasts for seven blocks. At a cutting speed of 250 ft/min, the tool lasts for 47 blocks. Determine n and C in the Taylor tool life equation. Ignore the effect of the approach distance given by Equation (21.18).

Solution: $N_1 = v/\pi D = 500(12)/6.0\pi = 318.3$ rev/min
$f_r = Nfn_t = 318.3(0.008)(12) = 30.56$ in/min
$T_m = L/f_r = 22/30.56 = 0.720$ min
$T_1 = 7T_m = 7(0.720) = 5.04$ min when $v_1 = 500$ ft/min
$N_2 = 250(12)/6.0\pi = 159.15$ rev/min
$f_r = Nfn_t = 159.15(0.008)(12) = 15.28$ in/min
$T_m = 22/15.28 = 1.44$ min
$T_2 = 47T_m = 47(1.44) = 67.68$ min when $v_2 = 250$ ft/min
$n = \ln(v_1/v_2)/\ln(T_2/T_1) = \ln(500/250)/\ln(67.68/5.04) = 0.693/2.597=$ **0.267**
$C = vT^n = 500(5.04\,)^{0.267} = 500(1.5397) =$ **769.8 ft/min**
Check: $C = vT^n = 250(67.68\,)^{0.267} = 250(3.0793) = 769.8$
The tool life equation is $vT^{0.267} = 769.8$

22.10 (SI units) In a production turning operation, the work part diameter = 102 mm and length = 400 mm long. A feed of 0.26 mm/rev is used in the operation. If cutting speed = 3.0 m/s, the tool must be changed every 5 work parts; but if cutting speed = 2.0 m/s, the tool can be used to produce 22 pieces between tool changes. Determine the Taylor tool life equation for this job.

Solution: (1) $T_m = \pi(102\text{ mm})(400\text{ mm})/(3.0 \times 10^3\text{ mm/s})(0.26\text{ mm}) = 164.33\text{ s} = 2.739$ min
$T = 5(2.739) = 13.69$ min

(2) $T_m = \pi(102\text{ mm})(400\text{ mm})/(2.0 \times 10^3\text{ mm/s})(0.26\text{ mm}) = 246.49\text{ s} = 4.108$ min
$T = 22(4.108) = 90.38$ min

(1) $v = 3$ m/s = 180 m/min
(2) $v = 2$ m/s = 120 m/min
(1) $180(13.69)^n = C$
(2) $120(90.38)^n = C$

$180(13.69)^n = 120(90.38)^n$
$\ln 180 + n \ln(13.69) = \ln 120 + n \ln(90.38)$
$5.1929 + 2.617\, n = 4.7875 + 4.504\, n$
$5.1929 – 4.7875 = (4.504 – 2.617)\, n$
$0.4054 = 1.887\, n$ **n = 0.215**
$C = 180\ (13.69)^{0.215}$ **C = 316 m/min**
Check: $C = 120(90.38\ )^{0.215} = 120(2.6336) = 316$
The tool life equation is $vT^{0.215} = 316$

22.11 (SI units) The n and C values in Table 22.2 are based on a feed rate of 0.25 mm/rev and a depth of cut = 2.5 mm. Determine how many cubic mm of steel would be removed for each of the following tool materials, if a 10-min tool life were required in each case: (a) plain-carbon steel, (b) high-speed steel, (c) cemented carbide, and (d) ceramic. Use of a spreadsheet calculator is recommended.

Solution: (a) For plain-carbon steel from Table 22.2, $n = 0.10$, $C = 20$ m/min
$v = 20/10^{0.1} = 20/1.259 = 15.886$ m/min
$R_{MR} = 15.886(10^3)(0.25)(2.50) = 9.9288(10^3)$ mm^3/min
For 10 min, metal removed = $10(9.9288)(10^3)$ = **~99(10^3) mm^3**

(b) HSS: $n = 0.125$, $C = 70$ m/min
$v = 70/10^{0.125} = 70/1.333 = 52.513$ m/min
$R_{MR} = 52.513(10^3)(0.25)(2.50) = 32.821(10^3)$ mm^3/min
For 10 min, metal removed = $10(32.821(10^3))$ = **~328(10^3) mm^3**

(c) Cemented carbide: $n = 0.25$, $C = 500$ m/min
$v = 500/10^{0.25} = 500/1.778 = 281.215$ m/min
$R_{MR} = 281.215(10^3)(0.25)(2.50) = 175.759(10^3)$ mm^3/min
For 10 min, metal removed = $10(175.759(10^3))$ = **~1,757(10^3)) mm^3**

(d) Ceramic: $n = 0.60$, $C = 3000$ m/min
$v = 3000/10^{0.6} = 3000/3.981 = 753.58$ m/min
$R_{MR} = 753.58\ (10^3)(0.25)(2.50) = 470.987(10^3)$ mm^3/min
For 10 min, metal removed = $10(470.987\ (10^3))$ = **~4,709(10^3) mm^3**

22.12 **(A)** (SI units) The outside diameter of a cylinder made of titanium alloy is to be turned. The starting diameter = 400 mm, and length = 1100 mm. Feed = 0.35 mm/rev, and depth of cut = 2.5 mm. The cut will be made with a cemented carbide tool whose Taylor tool life parameters are $n = 0.24$ and $C = 450$. Units for the Taylor equation are min for tool life and m/min for cutting speed. Compute the cutting speed that will allow the tool life to be 10% longer than the machining time for this part.

Solution: In this problem the specification is for $T = 1.10T_m$, where T_m = machining time per piece and T = tool life. Both of these times must be expressed in terms of cutting speed.
$T_m = \pi DL/fv$ and $T = (C/v)^{1/n}$
$T_m = \pi(400)(1100)(10^{-6})/0.35(10^{-3})v = 3949/v = 3949\ (v)^{-1}$
$T = (450/v)^{1/.24} = (450/v)^{4.1667} = 450^{4.1667}(v)^{-4.1667} = 1135(10^8)(v)^{-4.1667}$
Setting $1.10T_m = T$: $1.10(3949)v^{-1} = 1135(10^8)(v)^{-4.1667}$
$v^{3.1667} = 0.2613(10^8)$
$v = \{0.2613(10^8)\}^{1/3.1667} = \{0.2613(10^8)\}^{0.3158}$ = **220 m/min**

Check: $T_m = 3949/(220) = 17.4$ min
$T = (450/220)^{1/.24} = (2.0455)^{4.1667} = 19.7$ min, which is 10% longer than T_m

22.13 (SI units) The work part in a turning operation is 88 mm in diameter and 550 mm long. A feed of 0.30 mm/rev is used in the operation. If cutting speed = 3.3 m/s, the tool must be changed every three work parts; but if cutting speed = 2.2 m/s, the tool can be used to produce 14 parts between tool changes. Find the cutting speed that will allow one tool to be used for a batch size of 40 parts, which is the size of the next order for these parts.

Solution: (1) $v = 3.3$ m/s = 198 m/min
$T_m = \pi(0.088\text{ m})(0.55\text{ m})/(198\text{ m/min})(0.00030\text{ m}) = 2.56$ min
$T = 3(2.56) = 7.68$ min
(2) $v = 2.2$ m/s = 132 m/min
$T_m = \pi(0.088\text{ m})(0.55\text{ m})/(132\text{ m/min})(0.00030\text{ mm}) = 3.84$ min
$T = 14(3.84) = 53.76$ min

(1) $198(7.68)^n = C$
(2) $132(53.76)^n = C$
$198(7.68)^n = 132(53.76)^n$
$\ln 198 + n \ln(7.68) = \ln 132 + n \ln(53.76)$
$5.288 + 2.039\, n = 4.883 + 3.984\, n$
$5.288 - 4.883 = (3.984 - 2.039)\, n$
$0.405 = 1.946\, n$ $\qquad$ $\boldsymbol{n = 0.208}$
$C = 198(7.68)^{0.208}$ $\qquad$ $C = 302.6$

Check: $132(53.76)^{0.208} = 302.5$ Close enough. use $\boldsymbol{C = 302.6}$

Set $T = 40\, T_m$
$vT^{0.208} = 302.6$, $T^{0.208} = 302.6/v$, $T = (302.6/v)^{1/0.208} = (302.6/v)^{4.805} = 8.3257(10)^{11}/v^{4.805}$
$T_m = \pi(0.088)(0.55)/0.00030\, v = 506.84/v$
$8.3257(10)^{11}/v^{4.805} = 40(506.84/v) = 20{,}273.6/v$
$8.3257(10)^{11}/v^{3.805} = 20{,}273.6$
$v^{3.805} = 8.3257(10)^{11}/20{,}273.6 = 41{,}066{,}707$
$v = (41{,}066{,}707)^{1/3.805} = (41{,}066{,}707)^{0.2628} =$ **100.2 m/min**

Check: $T_m = 506.84/100.2 = 5.06$ min, $40T_m = 202.3$ min
$T = (302.6/100.2)^{4.805} = (3.02)^{4.805} = 202.5$ min (Close enough!)

22.14 (SI units) The machine shop has received an order to turn three alloy steel cylinders. Starting diameter = 250 mm and length = 625 mm. Feed = 0.30 mm/rev, and depth of cut = 2.5 mm. A coated carbide cutting tool will be used whose Taylor tool life parameters are $n = 0.25$ and $C = 700$, where the units are min for tool life and m/min for cutting speed. Compute the cutting speed that will allow the tool life to be just equal to the cutting time for the three parts.

Solution: In this problem the specification is for $3T_m = T$, where T_m = machining time per piece and T = tool life. Both of these times must be expressed in terms of cutting speed.
$T_m = \pi DL/fv$ and $T = (C/v)^{1/n}$
$T_m = \pi(250)(625)(10^{-6})/0.30(10^{-3})v = 1636.25/v = 1636.25\,(v)^{-1}$
$3T_m = 3(1636.25\,(v)^{-1}) = 4908.7(v)^{-1}$
$T = (700/v)^{1/.25} = (700/v)^{4.0} = 700^{4.0}(v)^{-4.0} = 2.401(10^{11})(v)^{-4.0}$

Setting $3T_m = T$: $4908.7v^{-1} = 2.401(10^{11})(v)^{-4.0}$
$v^{3.0} = 2.401(10^{11}) = 48{,}913{,}154$
$v = (48{,}913{,}154)^{1/3.0} =$ **365.7 m/min**

Check: $3T_m = 4908.7/365.7 = 13.42$ min
$T = (700/365.7)^{1/.25} = (1.9141)^{4.0} = 13.42$ min

Tooling Applications

22.15 High-speed steel is the tool material specified for a certain finish turning operation in the lathe section of the machine shop. The trouble is that tool life is much shorter than the foreman thinks it should be. A lubricant-type cutting fluid is used in the operation, and the machine operator complains of fumes emanating from the fluid. (a) Analyze the problem and (b) recommend some changes that might be made to solve it.

Solution: (a) High speed steel is vulnerable to temperature failure when cutting too fast in a continuous machining operation like turning. Short tool life and fumes coming from the lubricant type cutting fluid support the notion that cutting speed is too high.

(b) Recommendations based on Table 22.6: (1) reduce cutting speed to reduce cutting temperature; (2) use a coolant type cutting fluid rather than a lubricant because temperature failure seems to be the problem, not gradual wear; (3) reduce feed and/or depth; and (4) use a carbide or ceramic tool material instead of high speed steel in this finish turning operation.

22.16 Specify the ANSI C-grade or grades (C1 through C8 in Table 22.4) of cemented carbide for each of the following situations: (a) cutting the threads on the inlet and outlet of a large brass valve, (b) turning the diameter of a high-carbon steel shaft from 10.7 cm (4.2 in) to 8.9 cm (3.5 in), (c) making a final face milling pass using a shallow depth of cut and feed on a titanium part, and (d) boring out the holes of an alloy steel part prior to honing.

Solution: (a) Brass limits the choice of grades to C1 through C4. This is a finishing operation that could use C3 or C4.

(b) High carbon steel limits choice to grades C5 through C8. A large amount of material is being removed so it is a roughing cut. C5 or C6 could be used, depending on the finish required after the process is complete.

(c) Titanium limits the choice of grades to C1 through C4. Small feed and depth of cut indicate a finish pass. Depending on the finish requirements, C3 or C4 would be selected.

(d) Alloy steel limits the choice of grades to C5 through C8. Boring cylinders requires precision finishing. Choose either C7 or C8.

22.17 The machine shop limits the number of cemented carbide grades to four for inventory control purposes. The chemical compositions of these grades are as follows: Grade 1 contains 95% WC and 5% Co; Grade 2 contains 82% WC, 4% Co, and 14% TiC; Grade 3 contains 80% WC, 10% Co, and 10% TiC; and Grade 4 contains 89% WC and 11% Co. Specify the grade that should be used for the (a) rough machining of gray cast iron, (b) finish turning of unhardened steel, (c) rough milling of aluminum, and (d) finish turning of brass. For each case, explain your recommendation.

Solution: (a) Machining cast iron. Cast iron is included with the non-steel grades. Specify grade 4 for roughing.

(b) Finish turning of unhardened steel. Specify a steel-cutting grade suitable for finishing. This is a grade with TiC and low cobalt. Choose grade 2.

(c) Rough milling of aluminum. Specify a non-steel roughing grade. This is a grade with no TiC and high cobalt. Choose grade 4.

(d) Finish turning of brass. Specify a non-steel finishing grade. This is a grade with no TiC and low cobalt. Choose grade 1.

22.18 List the ISO R513-1975(E) group (letter and color in Table 22.6) and whether the number would be toward the lower or higher end of the ranges for each of the following situations: (a) milling the head gasket surface of an aluminum cylinder head of an automobile motor (cylinder head has a hole for each cylinder and must be very flat and smooth to mate up with the block), (b) rough turning a hardened steel shaft, (c) milling a fiber-reinforced polymer composite that requires a precise finish, and (d) milling the rough shape in a die made of steel before it is hardened.

Solution: (a) Aluminum would be the K (red) group. Milling the surface with large holes in it will create shock loading on the tool. This will require higher toughness. Because it is a finish cut, it will require higher hardness. A mid-range number will provide both. Move towards the low numbers for higher hardness if possible.

(b) Hardened steel shaft would indicate group P (blue). Rough cut would require higher toughness so choose a higher number.

(c) Composite is a nonmetallic and would use group K (red). Precise machining would require a high hardness (lower number).

(d) Steel would indicate the P (blue) group. Rough milling would indicate a higher toughness and thus a high number.

22.19 A turning operation is performed on a steel shaft with diameter = 127 mm (5.0 in) and length = 813 mm (32 in). A slot or keyway has been milled along its entire length. The turning operation reduces the shaft diameter. For each of the following tool materials, indicate whether it is a reasonable candidate to use in the operation: (a) plain-carbon steel, (b) high-speed steel, (c) cemented carbide, (d) ceramic, and (e) sintered polycrystalline diamond. For each material that is not a good candidate, give the reason why it is not.

Solution: The lengthwise slot results in an interrupted cut, so toughness is important in the tool material.

(a) Plain-carbon steel: not economical because of low cutting speeds.

(b) HSS: this is a reasonable candidate; it has good toughness for the interrupted cut.

(c) Cemented carbide: this is a reasonable candidate; it must be a steel cutting grade with high toughness (high cobalt content).

(d) Ceramic: this is not a good candidate because of its low toughness; it is likely to fracture during interrupted cutting.

(e) Sintered polycrystalline diamond: SPD is not suitable for cutting steel.

Cutting Fluids

22.20 (USCS units) In a milling operation with no coolant, a cutting speed of 400 ft/min is used. The current cutting conditions (dry) yield Taylor tool life equation parameters of $n = 0.25$ and $C = 1200$ (ft/min). When a coolant is used in the operation, the cutting speed can be increased by 10% and still maintain the same tool life. Assuming n does not change with the addition of coolant, what is the resulting change in the value of C?

Solution: Find the present tool life T
$vT^n = C$; $T = (C/v)^{(1/n)}$
$T = (1200/400)^{(1/.25)} = 3.0^{4.0} = 81$ min
After coolant, the new cutting speed would be 400(1+.10) = 440
If the tool life stays the same, $C = vT^n = 440(81)^{.25} = 1320$
% increase in $C = (1320 – 1200)/1200 =$ **10%**

Note: When viewing the log-log plot of the Taylor Tool Life curve, it is a straight line. Since n, the slope, is not affected by the coolant, the coolant effectively raises the line on the graph. Raising the curve so that it increases the value of v by a certain percentage will increase C by the same percentage. This is true independent of the values of n and C.

22.21 **(A)** (SI units) In a turning operation using high-speed steel tooling, cutting speed = 100 m/min. The Taylor tool life equation has parameters $n = 0.125$ and $C = 120$ (m/min) when the operation is performed dry. When a coolant is used in the operation, the value of C is increased by 15%. Determine the percent increase in tool life that results if the cutting speed is maintained at 100 m/min.

Solution: Dry: $100(T)^{0.125} = 120$
$T = (120/100)^{1/.125} = (1.2)^8 = 4.3$ min
With coolant: $100(T)^{0.125} = 120(1 + 15\%) = 120(1.15) = 138$
$T = (138/100)^{1/.125} = (1.38)^8 = 13.15$ min
Increase = (13.15 – 4.3)/4.3 = 2.06 = **206%**

22.22 Cemented carbide cutting inserts are used in a production milling operation to remove significant amounts of metal from a steel sand casting. This roughing operation is performed at low cutting speed, high depth and feed, and no cutting fluid is used. The problem is that the inserts wear out rapidly, and the foreman believes that a semichemical fluid should be used to reduce cutting temperature. (a) Analyze the problem and (b) recommend some changes that might solve it.

Solution: (a) The problem is excessive wear on the carbide tooling that results from the abrasive nature of sand castings made of steel.

(b) Recommendations: Surely a cutting fluid would be beneficial, but a semichemical fluid would better address temperature problems than wear problems. A lubricant type cutting fluid should be used to mitigate the wearing action of the work material on the tool. If a lubricant is not attractive, then an emulsifiable oil should be used with perhaps less water than usually recommended to increase the lubricating qualities of the fluid. Other changes that might help include reducing speed and feed.

22.23 (SI units) A high-speed steel 6.0-mm-diameter twist drill is used in a production drilling operation on mild steel. A cutting oil is applied by the operator by brushing the lubricant onto the drill point and flutes prior to each hole. The cutting conditions are: speed = 25 m/min, feed = 0.10 mm/rev, and hole depth = 42 mm. The foreman says that the "speed and feed are right out of the handbook" for this work material. Nevertheless, he also says, "the chips are clogging in the flutes, resulting in friction heat, and the drill bit is failing prematurely due to overheating." (a) Analyze the problem and (b) recommend some changes that might be made to solve it.

Solution: (a) There are several problems here. First, the depth-to-diameter ratio is 42:6 = 7:1, which is greater than the 4:1 that is usually recommended. As a consequence the chips produced in the hole are having difficulty exiting, thus causing overheating of the drill. Second, the manual method of applying the cutting oil may not be particularly effective. Third, with overheating as a problem, the cutting oil may not be removing heat from the operation effectively.

(b) Recommendation: The 7:1 depth-to-diameter ratio is a given, a requirement of the drilling operation, and it is assumed that this cannot be changed. The twist drill might be operated in a peck-drilling mode to solve the chip clogging problem. Peck-drilling means drilling for a distance approximately equal to one drill diameter, then retracting the drill, then drilling some more, etc. A twist drill with a fluid hole could be used to more effectively deliver the cutting fluid to the drill point to help extract the chips. Finally, an emulsified oil might be tried in the operation, one with good lubricating qualities, as a substitute for the cutting oil. Since overheating is a problem, it makes sense to try a coolant.