24 GRINDING AND OTHER ABRASIVE PROCESSES

Review Questions

24.1 Why are abrasive processes technologically and commercially important?

Answer. Important reasons include (1) applications on all types of materials, (2) very fine finishes, and (3) close tolerances.

24.2 What are the five basic parameters of a grinding wheel?

Answer. The parameters are (1) abrasive material, (2) grit size, (3) bonding material, (4) wheel structure, which refers to the relative spacing of grains, and (5) wheel grade, which refers to the bond strength of the wheel in retaining abrasive grains.

24.3 What are the principal abrasive materials used in grinding wheels?

Answer. The most important abrasive grit materials include (1) aluminum oxide, (2) silicon carbide, (3) cubic boron nitride, and (4) diamond.

24.4 Name some important bonding materials used in grinding wheels.

Answer. The bonding materials in grinding wheels are (1) vitrified bond - clay and ceramics, (2) silicate, (3) rubber, (4) resinoid, (5) shellac, and (6) metallic.

24.5 What is *wheel structure*?

Answer. Wheel structure indicates the relative spacing of the abrasive grains in the wheel. An open structure is one in which the grains are far apart, and a dense structure indicates that the grains are close together.

24.6 What is *wheel grade*?

Answer. Wheel grade refers to the wheel's ability to retain abrasive grains during cutting. It indicates the bond strength of the bonding material used to shape the wheel. A soft grade indicates that the grains are released easily from the bonding material. A hard wheel is one which retains the abrasive grains.

24.7 Why are specific energy values so much higher in grinding than in traditional machining processes such as milling?

Answer. Reasons for higher specific energy in grinding include: (1) size effect - smaller chip size means higher specific energy; (2) extremely negative rake angles on the abrasive particles in a grinding wheel; and (3) not all of the grains in the wheel surface are engaged in cutting; some are plowing or deforming the surface while others are simply rubbing and creating friction at the surface of the work.

24.8 Grinding creates high temperatures. How is temperature harmful in grinding?

Answer. High temperatures in grinding create surface burns and cracks. They can also soften the surfaces of work parts that have been heat treated for high hardness.

24.9 What are the three mechanisms of grinding wheel wear?

Answer. The mechanisms are (1) grain fracture, in which a portion of the grain breaks off during cutting; (2) attritious wear, in which the grains become dull during cutting; and (3) bond failure, in which the grains are pulled out of the bonding material.

24.10 What is *dressing*, in reference to grinding wheels?

Answer. Dressing is a procedure applied to worn grinding wheels to break off dull grits and expose fresh grits, and to remove chips of work material that have become clogged in the wheel. It uses a rotating disk or abrasive stick held against the wheel while it rotates.

24.11 What is *truing*, in reference to grinding wheels?

Answer. Truing is similar to dressing, but it also restores the ideal cylindrical shape to the wheel. It uses a diamond-pointed tool fed slowly and precisely across the wheel while it rotates.

24.12 What abrasive material would one select for grinding a cemented carbide cutting tool?

Answer. Choose a diamond wheel.

24.13 What are the functions of a grinding fluid?

Answer. Functions of a grinding fluid include (1) reducing friction, (2) removing heat, (3) washing away chips, and (4) reducing workpiece temperature.

24.14 What is *centerless grinding*?

Answer. Centerless grinding is a grinding operation in which cylindrical work parts (e.g., rods) are fed between two rotating wheels: (1) a high speed grinding wheel and (2) a low speed regulating wheel which is tilted at a slight angle to control the feed-through rate.

24.15 How does creep feed grinding differ from conventional grinding?

Answer. In creep feed grinding, the depth of cut is very high - several thousand times higher than conventional grinding - and the feed rates are lower by about the same proportion.

24.16 How does abrasive belt grinding differ from a conventional surface grinding operation?

Answer. Instead of a grinding wheel, abrasive belt grinding uses abrasive particles bonded to a flexible cloth belt loop which is moved around a pulley system to obtain the speed motion. Parts are pressed against the belt to accomplish grinding.

24.17 Name some abrasive operations available to achieve very good surface finishes.

Answer. High finish abrasive processes include honing, lapping, superfinishing, buffing, and polishing.

Problems

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

24.1 **(A)** (SI units) Wheel diameter = 150 mm, and infeed = 0.05 mm in a surface grinding operation. Wheel speed = 1500 m/min, work speed = 0.30 m/s, and crossfeed = 5 mm. The number of active grits per area of wheel surface = 40 grits/cm^2. Determine the (a) average length per chip, (b) metal-removal rate, and (c) number of chips formed per unit time for the portion of the operation when the wheel is engaged in the work.

Solution: (a) $l_c = (Dd)^{0.5} = (150 \times 0.05)^{0.5} =$ **2.74 mm**

(b) $R_{MR} = v_w wd$ = (0.30 m/s)(10^3 mm/m)(5.0 mm)(0.05 mm) = 75 mm^3/s = **4500 mm^3/min**

(c) $n_c = vwC$ = (1500 m/min)(10^3)(5.0 mm)(40 grits/cm^2)(10^{-2}) = **3,000,000 chips/min**

24.2 (USCS units) In a surface grinding operation, wheel diameter = 8.0 in, wheel width = 1.0 in, wheel speed = 6000 ft/min, work speed = 40 ft/min, infeed = 0.002 in, and crossfeed = 0.20 in. The number of active grits per square inch of wheel surface = 400. Determine the (a) average length per chip, (b) metal removal rate, and (c) number of chips formed per unit time for the portion of the operation when the wheel is engaged in the work.

Solution: (a) $l_c = (Dd)^{0.5} = (8.0 \times 0.002)^{0.5} = (0.016)^{0.5} =$ **0.1265 in**

(b) $R_{MR} = v_w wd = (40 \times 12)(0.20)(0.002) =$ **0.192 in^3/min**

(c) $n_c = vwC = (6000 \times 12)(0.2)(400) =$ **5,760,000 chips/min**

24.3 (SI units) In an external cylindrical grinding operation on a hardened steel tube whose outside radius = 42.5 mm, the grinding wheel diameter = 125 mm and wheel width = 20 mm. The workpiece rotates at a surface speed of 25 m/min, the wheel rotates at 1800 rev/min, infeed (depth of cut) = 0.05 mm, and traverse feed = 0.50 mm/rev. There are 50 active grits/cm^2 of wheel surface, and the operation is performed dry. Determine the (a) volume rate of metal removed, (b) number of chips formed per unit time, and (c) average volume per chip. (d) If the tangential cutting force on the work = 45 N, compute the specific energy in this operation.

Solution: (a) $R_{MR} = v_w wd = (25 \text{ m/min})(10^3)(0.50 \text{ mm})(0.05 \text{ mm}) =$ **625 mm^3/min**

(b) $n_c = vwC$
$v = N\pi D = (1800 \text{ rev/min})(125\pi \text{ mm/rev}) = 706{,}858$ mm/min
$n_c = (706{,}858 \text{ mm/min})(0.5 \text{ mm})(50 \text{ grits/cm}^2)(10^{-2}) =$ **176,715 grits/min (chips/min)**

(c) Average volume per chip = (625 mm^3/min)/(176,715 chips/min) = **0.0035 mm^3/chip**

(d) $U = F_c v/R_{MR}$
$v = 706{,}858$ mm/min = 706.9 m/min
$U = 45(706.9)/625 =$ **50.9 N-m/mm^3**

24.4 **(A)** (USCS units) An 8-in-diameter grinding wheel rotates at a surface speed of 4000 ft/min in a surface grinding job performed on a flat piece of 4340 steel with hardness = 325 BHN. There are 300 active grits/in^2 of wheel surface, and the operation is performed dry. Infeed = 0.0015 in per pass, crossfeed = 0.20 in, and the reciprocating speed of the work is 30 ft/min. Determine the (a) length of contact between the wheel and the work, (b) volume rate of metal removed, (c) number of chips formed per unit time, and (d) average volume per chip? (e) If the tangential cutting force on the workpiece = 23 lb, what is the specific energy calculated for this job?

Solution: (a) $l_c = (Dd)^{0.5} = (8 \times 0.0015)^{0.5} = (0.012)^{0.5} =$ **0.1095 in**

(b) $R_{MR} = v_w wd = (30 \times 12)(0.20)(0.0015) =$ **0.108 in^3/min**

(c) $n_c = vwC = (4000 \times 12)(0.20)(300) =$ **2,880,000 chips/min**

(d) Avg vol/chip = (0.108 in^3/min)/(2,880,000 chips/min) = 0.000000037 in^3 = **37(10^{-9}) in^3**

(e) $U = F_c v/R_{MR} = 23(4000 \times 12)/0.108 =$ **10,222,222 in-lb/in^3 = 25.8 hp/(in^3/min)**

24.5 (SI units) An internal cylindrical grinding operation is used to finish an internal bore from an initial diameter of 250.00 mm to a final diameter of 252.1 mm. The bore is 120 mm long. A grinding wheel with an initial diameter of 150.00 mm and a width of 20.00 mm is used. After the operation, the diameter of the grinding wheel has been reduced to 149.8 mm. Determine the grinding ratio in this operation.

Solution: GR = (volume of work material removed)/(volume of wheel removed)
Volume of work material removed = $(\pi/4)(120)(252.1^2 - 250.0^2) = 99{,}376$ mm^3
Volume of wheel removed = $(\pi/4)(20)(150^2 - 149.8^2) = 941.8$ mm^3
GR = 99,376/941.8 = **105.5**

24.6 (SI units) In a centerless grinding operation, the grinding wheel diameter = 300 mm, and the regulating wheel diameter = 125 mm. The grinding wheel rotates at 1500 rev/min, and the regulating wheel rotates at 200 rev/min. The inclination angle of the regulating wheel = 2.0°. Determine the production rate of cylindrical work parts that are 12.0 mm in diameter and 100 mm long.

Solution: From Equation (24.11), $f_r = \pi D_r N_r \sin I$
$f_r = \pi(125)(200) \sin 2.0° = 25{,}000\pi(0.0349) = 2741$ mm/min
Parts production rate = (2741 mm/min)/(100 mm/pc) = **27.4 pc/min**

24.7 (SI units) A centerless grinding operation uses a regulating wheel that is 125 mm in diameter and rotates at 300 rev/min. At what inclination angle should the regulating wheel be set, if it is desired to feed a workpiece with length = 1.5 m and diameter = 12 mm through the operation in exactly 15 sec?

Solution: From Equation (24.11), $f_r = \pi D_r N_r \sin I$
f_r = 1.5 m per 15 sec = 0.10 m/s = 6.0 m/min
$f_r = \pi(125 \times 10^{-3})(300 \text{ rev/min}) \sin I = 117.81 \sin I$ (units are m/min)
6.0 m/min = 117.81 $\sin I$ m/min
$\sin I = 6.0/117.81 = 0.0509$ $\boldsymbol{I = 2.92°}$

24.8 **(A)** (USCS units) In a centerless grinding operation, the grinding wheel diameter = 10 in, and the regulating wheel diameter = 6.0 in. The grinding wheel rotates at 2000 rev/min, and the regulating wheel rotates at 200 rev/min. The inclination angle of the regulating wheel = 2.5°. Determine the production rate of cylindrical work parts whose diameter = 0.75 in and length = 6.0 in.

Solution: From Equation (24.11), $f_r = \pi D_r N_r \sin I = \pi(6.0)(200) \sin 2.5° = 164.44$ in/min
Parts feed at (6.0 in/part)/(164.44 in/min) = 0.0365 min/part = 2.19 sec/part
Production rate R_p = 1/0.0365 = **27.4 parts/min**

24.9 (USCS units) The regulating wheel diameter in a centerless grinding operation = 5.0 in. The inclination angle of the regulating wheel = 3.5°. The operation is used to grind the outside surface of cylindrical parts that are 3.5 in long. To meet the production schedule, these parts must be processed at the rate of 3000 pc/hr. Determine the required rotational speed of the regulating wheel that will satisfy this requirement.

Solution: From Equation (24.11), $f_r = \pi D_r N_r \sin I = \pi(5.0)N_r \sin 3.5° = 0.959N_r$ in/min
R_p = 3000 pc/hr = 50 pc/min
At L = 3.5 in/part, this is a throughfeed rate f_r = 50(3.5) = 175 in/min
175 in/min = $0.959N_r$ in/min
N_r = 175/0.959 = **182.5 rev/min**

24.10 **(A)** (SI units) It is desired to compare the cycle times required to grind a particular workpiece using traditional surface grinding and using creep feed grinding. The workpiece is 200 mm long, 30 mm wide, and 75 mm thick. To make a fair comparison, the grinding wheel in both cases is 250 mm in diameter and 35 mm wide, and rotates at 1500 rev/min. It is desired to remove 25 mm of material from the surface. When traditional grinding is used, the infeed is set at 0.025 mm, and the wheel traverses twice (forward and back) across the work surface during each pass before resetting the infeed. There is no crossfeed since the wheel width is greater than the work width. Each pass is made at a work speed of 12 m/min, but the wheel overshoots the part on both sides. With acceleration and deceleration, the wheel is engaged in the work for 50% of the time on each pass. When creep feed grinding is used, the depth is increased by 1000 and the forward feed is decreased by 1000. How long will it take to complete the grinding operation (a) with traditional grinding and (b) with creep feed grinding?

Solution: (a) Conventional surface grinding:
Time of engagement/pass = 200×10^{-3} m/(12 m/min) = 0.01667 min = 1 s
Forward and backward stroke = 2(1 s)/50% = 4 s
Number of passes to remove 25 mm = 25/0.025 = 1000 passes
Time to complete 1000 passes = 1000(4) = 4000 s = **66.67 min**

(b) Creep feed grinding:
Total length of feed = 200 mm + approach = $200 + (d(D-d))^{0.5}$
Given D = 250 mm and d = 25 mm, Total feed length = $200 + (25(250-25))^{0.5}$ = 275 mm
$f_r = (12 \times 10^3$ mm/min)/1000 = 12 mm/min
Time to feed = 275/12 = **22.917 min**

Note: Creep feed grinding requires about 1/3 the time of conventional surface grinding for the situation defined here.

24.11 In a certain grinding operation, the grade of the grinding wheel should be "M" (medium), but the only available wheel is grade "T" (hard). It is desired to make the wheel appear softer by making changes in cutting conditions. What changes would you recommend?

Solution: A hard wheel means that the grains are not readily pulled from the wheel bond. The wheel can be made to appear softer by increasing the force on the individual grits as given by Equation (24.8). According to this equation, the force on the abrasive grains will be increased by increasing work speed v_w, decreasing wheel speed v, and increasing infeed d.

24.12 An aluminum alloy is to be ground in an external cylindrical grinding operation to obtain a good surface finish. Specify the appropriate grinding wheel parameters and the grinding conditions for this job.

Solution: Grinding wheel specification:
Abrasive type: silicon carbide
Grain size: small = high grit size number
Bond material: shellac bond
Wheel structure: dense
Wheel grade: medium to hard
Wheel specification: **C-150-E-5-B**

Grinding conditions:
Wheel speed: high speed, around 1800 m/min (6000 ft/min)
Work speed: low, around 10 m/min (30 ft/min)
Infeed (depth of cut): low, around 0.012 mm (0.0005 in)
Crossfeed: low, around 1/6 of wheel width.

24.13 A high-speed steel broach (hardened) is to be resharpened to achieve a good finish. Specify the appropriate parameters of the grinding wheel for this job.

Solution: Grinding wheel specification:
Abrasive type: cubic boron nitride
Grain size: small - high grit size number
Bond material: vitrified bond
Wheel grade: soft to medium
Wheel specification: XX-**B-150-P-XY-V-**XZ-1/8, where XX, XY, and XZ are manufacturer's symbols.

24.14 Based on equations in the text, derive an equation to compute the average volume per chip formed in the grinding process.

Solution: From Equation (24.3), $R_{MR} = v_w wd$ (in^3/min)
From Equation (24.6), $n_c = vwC$ (chips/min)
Volume per chip = $R_{MR}/n_c = v_w wd/vwC = \boldsymbol{v_w d/vC}$