ME477: Manufacturing Processes
Fall 2005
Homework #3

Chapter 18: Multiple Choice Questions (18.2, 18.6, 18.8)
Problems (18.4, 18.11)
Chapter 19: Multiple Choice Questions (19.3, 19.8, 19.9)
Problems (19.6, 19.12, 19.16, 19.20, 19.25, 19.31, 19.34)
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Chapter 18:
Multiple Choice Questions
18.2 (b)
18.6 (a), (c), (e), and (f)
18.8 (b)

Problems
18.4 **Solution**: $\varepsilon = \ln(1.5/3.0) = \ln 0.5 = -0.69315$
Flow stress $Y_f = 40{,}000(0.69315)^{0.19} =$ **37,309 lb/in^2.**
Average flow stress $\bar{Y}_f = 40{,}000(0.69315)^{0.19}/1.19 =$ **31,352 lb/in^2.**

18.11 **Solution**: (a) strain rate = 200/100 = **2.0 s^{-1}**
(b) strain rate = 200/75 = **2.667 s^{-1}**
(c) strain rate = 200/51 = **3.922 s^{-1}**

Chapter 19:
Multiple Choice Questions
19.3 (a), (e), and (f)
19.8 (b)
19.9 (a), (c), and (d)

Problems
19.6 **Solution:** (a) To reduce from $t_o = 3.0$ in. to $t_f = 0.3$ in. in 8 stands, $3.0(1 - x)^8 = 0.3$
$(1 - x)^8 = 0.3/3.0 = 0.10$
$(1 - x) = (0.10)^{1/8} = 0.74989$
x = 1 - 0.74989 = **r = 0.2501 = 25.01% at each stand.**
(b) Forward slip $s = (v_f - v_r)/v_r$
$sv_r = v_f - v_r$
$(1 + s)v_r = v_f$
At stand 1: $(1 + s)v_{r1} = v_1$, where v_{r1} = roll speed, v_1 = exit speed of slab.
At stand 2: $(1 + s)v_{r2} = v_2$, where v_{r2} = roll speed, v_2 = exit speed of slab.
Etc.
At stand 8: $(1 + s)v_{r8} = v_8$, where v_{r8} = roll speed, v_8 = exit speed of slab.
By constant volume, $t_ow_ov_o = t_1w_1v_1 = t_2w_2v_2 = \ldots = t_8w_8v_8$
Since there is no change in width, $w_o = w_1 = w_2 = \ldots w_8$
Therefore, $t_ov_o = t_1v = t_2v_2 = \ldots = t_8v_8$

$t_o = 3.0$,
$3v_o = 3(1 - r)v_1 = 3(1 - r)^2v_2 = . . . 3(1 - r)^8v_8$, where r = 0.2501 as determined in part (a).
Since s is a constant, $v_{r1} : v_{r2} : . . . : v_{r8} = v_1 : v_2 : . . . : v_8$
Given that N_{r1} = 30 rev/min, $v_{r1} = \pi DN_{r1} = (2\pi \times 18/12)(30)$ = 282.78 ft/min
In general $N_r = (30/282.78) = 0.10609v_r$
N_{r2} = 0.10609 x 282.78/(1-r) = 0.10609 x 282.78/(1-0.2501) = **40 rev/min**
N_{r3} = 0.10609 x 282.78/$(1\text{-}r)^2$ = **53.3 rev/min**
N_{r4} = 0.10609 x 282.78/$(1\text{-}r)^3$ = **71.1 rev/min**
N_{r5} = 0.10609 x 282.78/$(1\text{-}r)^4$ = **94.9 rev/min**
N_{r6} = 0.10609 x 282.78/$(1\text{-}r)^5$ = **126.9.3 rev/min**
N_{r7} = 0.10609 x 282.78/$(1\text{-}r)^6$ = **168.5 rev/min**
N_{r8} = 0.10609 x 282.78/$(1\text{-}r)^7$ = **224.9 rev/min**
(c) Given v_o = 240 ft/min
v_1 = 240/(1-r) = 240/0.74989 = 320 ft/min
v_2 = 320/0.74989 = 426.8 ft/min
From equations for forward slip, $(1 + s)v_{r1} = v_1$
(1 + s)(282.78) = 320
(1 + s) = 320/282.78 = 1.132 **s = 0.132**
Check with stand 2: given v_2 = 426.8 ft/min from above
$N_{r2} = 0.10609v_{r2}$
Rearranging, $v_{r2} = N_{r2}/0.10609 = 9.426N_{r2}$ = 0.426(40) = 377.04 ft/min
(1 + s)(377.04) = 426.8
(1 + s) = 426.8/377.14 = 1.132 s = 0.132, as before
(d) Draft at stand 1 d_1 = 3.0(.2501) = **0.7503 in.**
Draft at stand 8 $d_8 = 3.0(1 - .2501)^7(.2501)$ = **0.10006 in.**
(e) Length of final strip $L_f = L_8$
$t_ow_oL_o = t_8w_8L_8$
Given that $w_o = w_8$, $t_oL_o = t_8L_8$
$3.0(10\text{ ft}) = 0.3L_8$ **L_8 = 100 ft**
$t_ow_ov_o = t_8w_8v_8$
$t_ov_o = t_8v_8$
v_8 = 240(3/0.3) = **2400 ft/min.**

19.12**Solution:** (a) Assumption: maximum possible draft is determined by the force capability of the
rolling mill and not by coefficient of friction between the rolls and the work.
Draft d = 1.5 - t_f
Contact length L = $(12d)^{0.5}$
$Y_f = 20,000(\varepsilon)^0/1.0$ = 20,000 lb/in^2
Force F = 20,000(10) $(12d)^{0.5}$ = 400,000 (the limiting force of the rolling mill)
$(12d)^{0.5}$ = 400,000/200,000 = 2.0
12 d = 2.0^2 = 4
d = 4/12 = 0.333 in.
(b) True strain $\varepsilon = \ln(1.5/t_f)$
$t_f = t_o$ -d = 1.5 - 0.333 = 1.167 in.
ε = ln(1.5/1.167) = ln 1.285 = **0.251**
(c) Given maximum possible power HP = 100 hp = 100 x 396000 (in-lb/min)/hp = 39,600,000 in-lb/min

Contact length L = $(12 \times 0.333)^{0.5}$ = 2.0 in.
P = 2πN(400,000)(2.0) = 5,026,548N in-lb/min
5,026,548N = 39,600,000
N = 7.88 rev/min
$v_r = 2\pi RN = 2\pi(12/12)(7.88)$ = **49.5 ft/min**

19.16 **Solution**: Volume of cylinder V = $\pi D^2L/4 = \pi(2.5)^2(4.0)/4$ = 19.635 in^3
We will compute the force F at selected values of height h: h = (a) 4.0, (b) 3.75, (c) 3.5, (d) 3.25, (e) 3.0, (f) 2.75, and (g) 2.5. These values can be used to develop the plot. The shape of the plot will be similar to Figure 21.13 in the text.
(a) At **h = 4.0**, we assume yielding has just occurred and the height has not changed significantly.
Use ε = 0.002 (the approximate yield point of metal).
At ε = 0.002, $Y_f = 25{,}000(0.002)^{0.22}$ = 6,370 lb/in^2
Adjusting the height for this strain, h = 4.0 - 4.0(0.002) = 3.992
A = V/h = 19.635/3.992 = 4.92 in^2
K_f = 1 + 0.4(.1)(2.5)/3.992 = 1.025
F = 1.025(6,370)(4.92) = **32,125 lb**
(b) At **h = 3.75**, ε = ln(4.0/3.75) = ln 1.0667 = 0.0645
$Y_f = 25{,}000(0.0645)^{0.22}$ = 13,680 lb/in^2
V = 19.635 in^3 calculated above.
At h = 3.75, A = V/h = 19.635/3.75 = 5.236 in^2
Corresponding D = 2.582 (from A = $\pi D^2/4$)
K_f = 1 + 0.4(.1)(2.582)/3.75 = 1.028
F = 1.028(13,680)(5.236) = **73,601 lb**
(c) At **h = 3.5**, ε = ln(4.0/3.5) = ln 1.143 = 0.1335
$Y_f = 25{,}000(0.1335)^{0.22}$ = 16,053 lb/in^2
At h = 3.5, A = V/h = 19.635/3.5 = 5.61 in^2
Corresponding D = 2.673 (from A = $\pi D^2/4$)
K_f = 1 + 0.4(.1)(2.673)/3.5 = 1.031
F = 1.031(16,053)(5.61) = **92,808 lb**
(d) At **h = 3.25**, ε = ln(4.0/3.25) = ln 1.231 = 0.2076
$Y_f = 25{,}000(0.2076)^{0.22}$ = 17,691 lb/in^2
At h = 3.25, A = V/h = 19.635/3.25 = 6.042 in^2
Corresponding D = 2.774 (from A = $\pi D^2/4$)
K_f = 1 + 0.4(.1)(2.774)/3.25 = 1.034
F = 1.034(17,691)(6.042) = **110,538 lb**
(e) At **h = 3.0**, ε = ln(4.0/3.0) = ln 1.333 = 0.2874
$Y_f = 25{,}000(0.2874)^{0.22}$ = 19,006 lb/in^2
At h = 3.0, A = V/h = 19.635/3.0 = 6.545 in^2

Corresponding D = 2.887 (from A = $\pi D^2/4$)
K_f = 1 + 0.4(.1)(2.887)/3.0 = 1.038
F = 1.038(19,006)(6.545) = **129,182 lb**
(f) At **h =2.75**, ε = ln(4.0/2.75) = ln 1.4545 = 0.3747
$Y_f = 25{,}000(0.3747)^{0.22}$ = 20,144 lb/in^2
V = 19.635 in^3 calculated above.
At h = 2.75, A = V/h = 19.635/2.75 = 7.140 in^2

Corresponding D = 3.015 (from $A = \pi D^2/4$)
$K_f = 1 + 0.4(.1)(3.015)/2.75 = 1.044$
F = 1.044(20,144)(7.140) = **150,136 lb**
(g) At **h = 2.5**, $\varepsilon = \ln(4.0/2.5) = \ln 1.60 = 0.470$
$Y_f = 25{,}000(0.470)^{0.22} = 21{,}174$ lb/in^2
At h = 2.5, A = V/h = 19.635/2.5 = 7.854 in^2
Corresponding D = 3.162 (from $A = \pi D^2/4$)
$K_f = 1 + 0.4(.1)(3.162)/2.5 = 1.051$
F = 1.051(21,174)(7.854) = **174,715 lb**

19.20**Solution**: Volume of work $V = \pi D_o$
$^2 h_o/4 = \pi(30)^2(30)/4 = 21{,}206$ mm^3.
Final area $A_f = 21{,}206/h_f$
$\varepsilon = \ln(30/h_f)$
$Y_f = 400\varepsilon^{0.2} = 400(\ln 30/h_f)^{0.2})$
$K_f = 1 + 0.4\mu(D_f/h_f) = 1 + 0.4(0.1)(D_f/h_f)$
Forging force $F = K_f Y_f A_f = (1 + 0.04D_f/h_f)(\ 400(\ln 30/h_f)^{0.2})(\ 21{,}206/h_f)$
Requires trial and error solution to find the value of $\mathbf{h_f}$ that will match the force of **1,000,000 N**.
(1) Try $h_f = 20$ mm
$A_f = 21{,}206/20 = 1060.3$ mm^2
$\varepsilon = \ln(30/20) = \ln 1.5 = 0.405$
$Y_f = 400(0.405)^{0.2} = 333.9$ MPa
$D_f = (4 \times 1060.3/\pi)^{0.5} = 36.7$ mm
$K_f = 1 + 0.04(36.7/20) = 1.073$
F = 1.073(333.9)(1060.3) = **380,050 N**
Too low. Try a smaller value of h_f to increase F.
(2) Try $h_f = 10$ mm.
$A_f = 21{,}206/10 = 2120.6$ mm^2
$\varepsilon = \ln(30/10) = \ln 3.0 = 1.099$
$Y_f = 400(1.099)^{0.2} = 407.6$ MPa
$D_f = (4 \times 2120.6/\pi)^{0.5} = 51.96$ mm
$K_f = 1 + 0.04(51.96/10) = 1.208$
F = 1.208(407.6)(2120.6) = **1,043,998 N**
Slightly high. Need to try a value of h_f between 10 and 20, closer to 10.
(3) Try $h_f = 11$ mm
$A_f = 21{,}206/11 = 1927.8$ mm^2
$\varepsilon = \ln(30/11) = \ln 2.7273 = 1.003$
$Y_f = 400(1.003)^{0.2} = 400.3$ MPa
$D_f = (4 \times 1927.8/\pi)^{0.5} = 49.54$ mm
$K_f = 1 + 0.04(51.12/11) = 1.18$
F = 1.18(400.3)(1927.8) = **910,653 N**
(4) By linear interpolation, try $h_f = 10 + (44/133) = 10.33$ mm
$A_f = 21{,}206/10.33 = 2052.8$ mm^2
$\varepsilon = \ln(30/10.33) = \ln 2.9042 = 1.066$
$Y_f = 400(1.066)^{0.2} = 405.16$ MPa
$D_f = (4 \times 2052.8/\pi)^{0.5} = 51.12$ mm

$K_f = 1 + 0.04(51.12/10.33) = 1.198$
F = 1.198(405.16)(2052.8) = **996,364 N**
(5) By further linear interpolation, try $h_f = 10 + (44/48)(0.33) = 10.30$
$A_f = 21{,}206/10.30 = 2058.8$ mm^2
$\varepsilon = \ln(30/10.30) = \ln 2.913 = 1.069$
$Y_f = 400(1.069)^{0.2} = 405.38$ MPa
$D_f = (4 \times 2058.8/\pi)^{0.5} = 51.2$ mm
$K_f = 1 + 0.04(51.2/10.3) = 1.199$
F = 1.199(405.38)(2058.8) = **1,000,553 N**
Close enough! Maximum height reduction = 30.0 - 10.3 = **19.7 mm**

19.25**Solution**: (a) $r_x = A_o/A_f = D_o^2/D_f^2 = (35)^2/(20)^2 =$ **3.0625**
(b) $\varepsilon = \ln r_x = \ln 3.0625 =$ **1.119**
(c) $\varepsilon_x = a + b \ln r_x = 0.8 + 1.4(1.119) =$ **2.367**
(d) $Y_f = 750(1.119)^{0.25}/1.25 = 493.7$ MPa
It is appropriate to determine the volume of metal contained in the cone of the die at the start of the extrusion operation, to assess whether metal has been forced through the die opening by the time the billet has been reduced from L = 75 mm to L = 70 mm. For a cone-shaped die with angle = 75°, the height h of the frustum is formed by metal being compressed into the die opening: The two radii are: $R_1 = 0.5D_o = 17.5$ mm and $R_2 = 0.5D_f = 10$ mm, and $h = (R_1 - R_2)/\tan 75 = 7.5/\tan 75 = 2.01$ mm
Frustum volume $V = 0.333\pi h(R_1^2 + R_1R_2 + R_2^2) = 0.333\pi(2.01)(17.5^2 + 10 \times 17.5 + 10^2) = 1223.4$ mm^3. Compare this with the volume of the portion of the cylindrical billet between L = 75 mm and L = 70 mm.
$V = \pi D_o^2 h/4 = 0.25\pi(35)^2(75 - 70) = 4810.6$ mm^3
Since this volume is greater than the volume of the frustum, this means that the metal has extruded through the die opening by the time the ram has moved forward by 5 mm.
L = 70 mm: pressure p = 493.7(2.367 + 2 x 70/35) = **3143.4 MPa**
L = 40 mm: pressure p = 493.7(2.367 + 2 x 40/35) = **2297.0 MPa**
L = 10 mm: pressure p = 493.7(2.367 + 2 x 10/35) = **1450.7 MPa**

19.31 **Solution**: (a) $r_x = A_o/A_f$
$A_o = 0.25\pi(50)^2 = 1963.75$ mm^2
$A_f = 0.25\pi(50^2 - 40^2) = 706.86$ mm^2
$r_x = 1963.75/706.86 =$ **2.778**
(b) To determine the die shape factor we need to determine the perimeter of a circle whose area is equal to that of the extruded cross-section, A = 706.86 mm^2. The radius of the circle is $R = (706.86/\pi)^{0.5} = 15$ mm, $C_c = 2\pi(15) = 94.25$ mm.
The perimeter of the extruded cross-section $C_x = \pi(50 + 40) = 90\pi = 282.74$ mm.
$K_x = 0.98 + 0.02(282.74/94.25)^{2.25} =$ **1.217**
(c) Volume of final cup consists of two geometric elements: (1) base and (2) ring.
(1) Base t = 5 mm and D = 50 mm. $V_1 = 0.25\pi(50)^2(5) = 9817.5$ mm^3
(2) Ring OD = 50 mm, ID = 40 mm, and h = 95 mm.
$V_2 = 0.25\pi(50^2 - 40^2)(95) = 0.25\pi(2500 - 1600)(95) = 67{,}151.5$ mm^3
Total $V = V_1 + V_2 = 9817.5 + 67{,}151.5 = 76{,}969$ mm^3
Volume of starting slug must be equal to this value V = 76,969 mm^3
$V = 0.25\pi(50)^2(h) = 1963.5h = 76{,}969$ mm^3

h = 39.2 mm
(d) $\varepsilon = \ln 2.778 = 1.0218$
$\varepsilon_x = 0.8 + 1.5(1.0218) = 2.33$
$Y_f = 400(1.0218)^{0.25}/1.25 = 321.73$ MPa
$p = K_x Y_f$
$\varepsilon_x = 1.217(321.73)(2.33) = 912.3$ MPa
$A_o = 0.25\pi(40)^2 = 1256.6$ mm^2
F = 912.3(1256.6) = **1,146,430 N**

19.34 **Solution**: (a) $r = (A_o - A_f)/A_o$
$A_o = 0.25\pi(0.50)^2 = 0.1964$ in^2
$A_f = 0.25\pi(0.35)^2 = 0.0962$ in^2
r = (0.1964 - 0.0962)/0.1964 = **0.51**
(b) Draw force F:
$\varepsilon = \ln(0.1964/0.0962) = \ln 2.0416 = 0.7137$
$Y_f = 45{,}000(0.7137)^{0.22}/1.22 = 34{,}247$ lb/in^2
$\phi = 0.88 + 0.12(D/L_c)$
D = 0.5(.50 + 0.35) = 0.425
$L_c = 0.5(0.50 - 0.35)/\sin 12 = 0.3607$
$\phi = 0.88 + 0.12(0.425/0.3607) = 1.021$
$F = A_f Y_f(1 + \mu/\tan\alpha)\phi(\ln A_o/A_f)$
F = 0.0962(34,247)(1 + 0.1/tan 12)(1.021)(0.7137) = **3530 lb**
(c) P = 3530(2 ft/sec x 60) = 423,600 ft/lb/min
HP = 423,600/33,000 = **12.84 hp**

Chapter 20:

Multiple Choice Questions
20.1 (b)
20.4 (a) and (c)
20.7 (a), (c), and (e)
20.10 (b)

Problems
20.3 **Solution**: From Table 20.1, a = 0.045. Thus, c = 0.045(3.2) = 0.144 mm
(a) Blanking punch diameter = D_b - 2c = 65 - 2(0.144) = **64.71 mm**
Blanking die diameter = D_b = **65 mm**
(b) Punching punch diameter = D_h = **30 mm**
Punching die diameter = D_h + 2c = 30 + 2(0.144) = **30.29 mm**

20.11 **Solution**: (a) R/t = (3/16)/(5/32) = 1.2. Therefore, $K_{ba} = 0.33$
$B = 2\pi(90/360)(0.1875 + 0.33 \times 0.15625) = 0.3756$ in.
Dimensions (lengths) of each end = 0.5(4.0 - 0.3756) = **1.8122 in.**
(b) Since the metal stretches during bending, its length will be greater after the bend than before. Its length before bending = 4.000 in. The stretched length of the bend along the neutral axis will be:
$B = 2\pi(90/360)(0.1875 + 0.5 \times 0.15625) = 0.4173$ in.

Therefore, the length of the neutral axis of the part will be 2(1.8122) + 0.4173 = **4.0417 in.**
(c) The operator should set the stop so that the tip of the V-punch contacts the starting blank at a distance = 2.000 in. from the end.

20.20 **Solution**: (a) DR = 7.5/4.0 = **1.875**
(b) t/D = 0.125/7.5 = **0.01667 = 1.667%**
(c) $F = \pi D_p t(TS)(D/D_p - 0.7) = \pi(4)(0.125)(60{,}000)(7.5/4 - 0.7) =$ **110,756 lb**.
(d) $F_h = 0.015Y\pi(D^2 - (D_p + 2.2t + 2R_d)^2)$
$F_h = 0.015(30{,}000)\pi(7.5^2 - (4 + 2.2 \times 0.125 + 2 \times 0.15625)^2) = 0.015(30{,}000)\pi(7.5^2 - 4.5875^2)$
F_h = 49,770 lb

20.30 **Solution**: (a) Use $\varepsilon = 0.002$ as start of yielding.
$F = LtY_f$
$Y_f = 70{,}000(0.002)^{0.25} = 14{,}803$ lb/in^2
F = (10)(0.12)(14,803) = **17,764 lb.**
(b) After stretching, the length of the piece is increased from 20.0 in. to $2(10^2 + 5^2)^{0.5} =$ 22.361 in.
$\varepsilon = \ln(22.361/20) = \ln 1.118 =$ **0.1116**
(c) At the final length of 22.361 in., the thickness of the sheet metal has been reduced to maintain constant volume, assuming width L = 10 in. remains the same during stretching.
$t_f = 0.12(20/22.361) = 0.1073$ in.
$Y_f = 70{,}000(0.1116)^{0.25} = 40{,}459$ lb/in^2
F = 10(0.1073)(40,459) = **43,413 lb.**
(d) $F_{die} = 2F \sin A$
$A = \tan^{-1}(5/10) = 26.57°$
F_{die} = 2(43,413) sin 26.57 = **38,836 lb.**