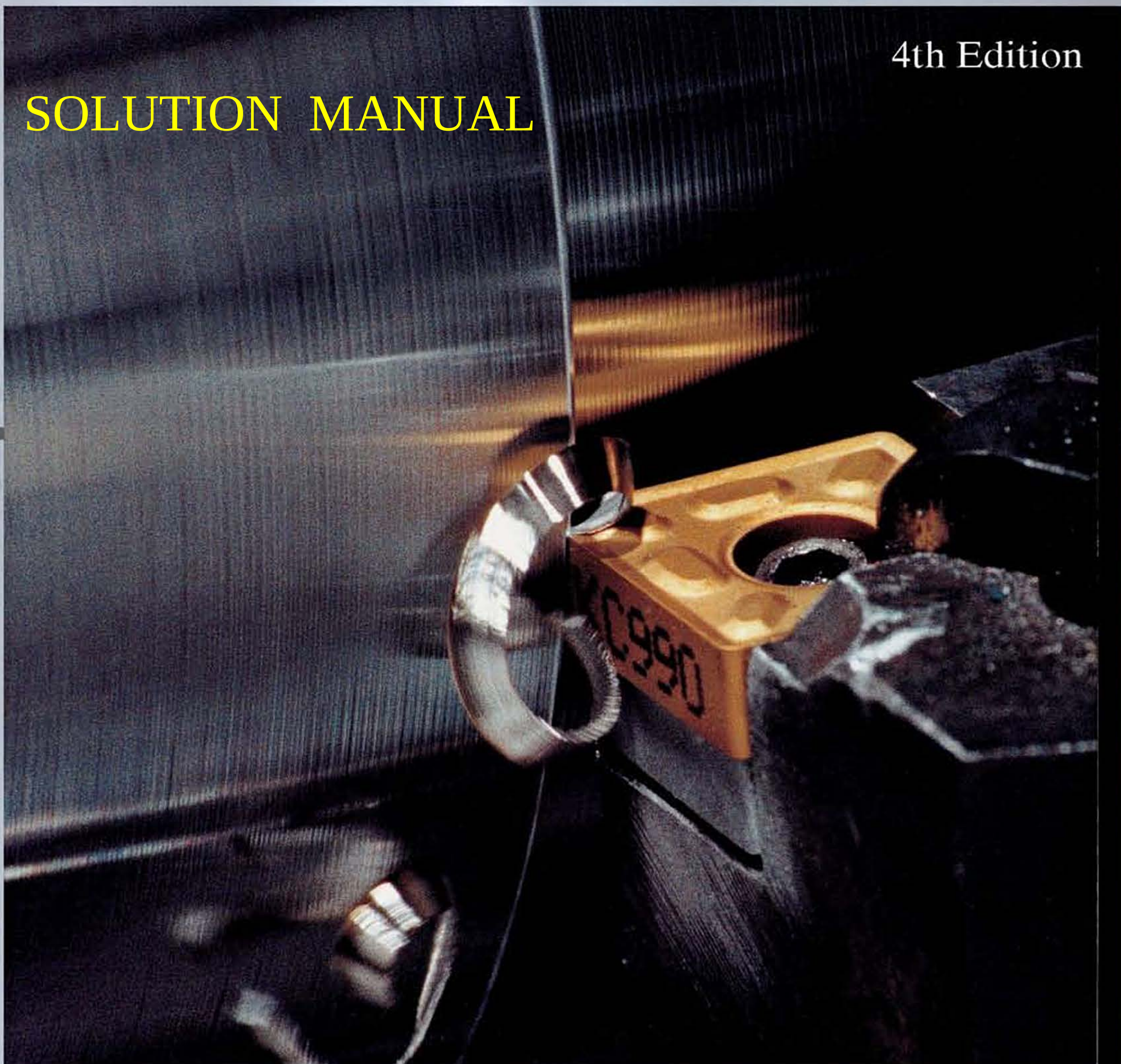
Fundamentals of Modern Manufacturing

Materials, Processes, and Systems



Mikell P. Groover

2 THE NATURE OF MATERIALS

Review Questions

2.1 The elements listed in the Periodic Table can be divided into three categories. What are these categories and give an example of each?

Answer. The three types of elements are metals (e.g., aluminum), nonmetals (e.g., oxygen), and semimetals (e.g., silicon).

2.2 Which elements are the noble metals?

Answer. The noble metals are copper, silver, and gold.

2.3 What is the difference between primary and secondary bonding in the structure of materials?

Answer. Primary bonding is strong bonding between atoms in a material, for example to form a molecule; while secondary bonding is not as strong and is associated with attraction between molecules in the material.

2.4 Describe how ionic bonding works?

Answer. In ionic bonding, atoms of one element give up their outer electron(s) to the atoms of another element to form complete outer shells.

2.5 What is the difference between crystalline and noncrystalline structures in materials?

Answer. The atoms in a crystalline structure are located at regular and repeating lattice positions in three dimensions; thus, the crystal structure possesses a long-range order which allows a high packing density. The atoms in a noncrystalline structure are randomly positioned in the material, not possessing any repeating, regular pattern.

2.6 What are some common point defects in a crystal lattice structure?

Answer. The common point defects are (1) vacancy - a missing atom in the lattice structure; (2) ion-pair vacancy (Schottky defect) - a missing pair of ions of opposite charge in a compound; (3) interstitialcy - a distortion in the lattice caused by an extra atom present; and (4) Frenkel defect - an ion is removed from a regular position in the lattice and inserted into an interstitial position not normally occupied by such an ion.

2.7 Define the difference between elastic and plastic deformation in terms of the effect on the crystal lattice structure.

Answer. Elastic deformation involves a temporary distortion of the lattice structure that is proportional to the applied stress. Plastic deformation involves a stress of sufficient magnitude to cause a permanent shift in the relative positions of adjacent atoms in the lattice. Plastic deformation generally involves the mechanism of slip - relative movement of atoms on opposite sides of a plane in the lattice.

2.8 How do grain boundaries contribute to the strain hardening phenomenon in metals?

Answer. Grain boundaries block the continued movement of dislocations in the metal during straining. As more dislocations become blocked, the metal becomes more difficult to deform; in effect it becomes stronger.

2.9 Identify some materials that have a crystalline structure.

Answer. Materials typically possessing a crystalline structure are metals and ceramics other than glass. Some plastics have a partially crystalline structure.

(b) Adjustments to reduce shrinkage include: (1) increase injection pressure, (2) increase compaction time, and (3) increase molding temperatures.

13.21 An injection molded polyethylene part has a dimension of 2.500 in. A new material, polycarbonate, is used in the same mold. What is the expected corresponding dimension of the polycarbonate molding?

Solution: For polyethylene the shrinkage is 0.025 in/in (from Table 13.1).
Die Cavity = $D_c = D_p + D_pS + D_pS^2$ = 2.500 + 2.500(0.025) + 2.500(0.025)^2 = 2.564 in
For polycarbonate, the shrinkage is 0.007 in/in
Part dimension = $D_c/(1 + S + S^2)$ = 2.564/(1 + 0.007 + 0.007^2) = **2.546 in**

Other Molding Operations and Thermoforming

13.22 The extrusion die for a polyethylene parison used in blow molding has a mean diameter of 18.0 mm. The size of the ring opening in the die is 2.0 mm. The mean diameter of the parison is observed to swell to a size of 21.5 mm after exiting the die orifice. If the diameter of the blow molded container is to be 150 mm, determine (a) the corresponding wall thickness of the container and (b) the wall thickness of the parison.

Solution: (a) $r_s = D_p/D_d$ = 21.5/18.0 = 1.194
$t_m = t_p\, D_p/D_m = r_s\, t_d\, D_p/D_m$ = (1.194)(2.0)(21.5)/150.0 = **0.342 mm**

(b) $t_p = r_s\, t_d$ = (1.194)(2.0) = **2.388 mm**

13.23 A parison is extruded from a die with outside diameter = 11.5 mm and inside diameter = 7.5 mm. The observed die swell is 1.25. The parison is used to blow mold a beverage container whose outside diameter = 112 mm (a standard size 2-liter soda bottle). (a) What is the corresponding wall thickness of the container? (b) Obtain an empty 2-liter plastic soda bottle and (carefully) cut it across the diameter. Using a micrometer, measure the wall thickness to compare with your answer in (a).

Solution: (a) D_d = (11.5 + 7.5)/2 = 9.5 mm, and t_d = (11.5 - 7.5)/2 = 2.0 mm
t_m = (1.25)^2(2.0)(9.5)/112 = **0.265 mm (= 0.010 in)**

(b) Measured value should be close to calculated value. Some wall thicknesses are less.

13.24 A blow-molding operation is used to produce a bottle with a diameter of 2.250 in and a wall thickness of 0.045 in. The parison has a thickness of 0.290 in. The observed die swell ratio is 1.30. (a) What is the required diameter of the parison? (b) What is the diameter of the die?

Solution: (a) $D_p = t_mD_m/t_p$ = (0.045)(2.250)/0.290 = **0.349 in**

(b) $D_d = D_p/r_s$ = 0.349/1.30 = **0.268 in**

13.25 An extrusion operation is used to produce a parison whose mean diameter = 27 mm. The inside and outside diameters of the die that produced the parison are 18 mm and 22 mm, respectively. If the minimum wall thickness of the blow-molded container is to be 0.40 mm, what is the maximum possible diameter of the blow mold?

Solution: D_d = (22 + 18)/2 = 20 mm, and t_d = (22 - 18)/2 = 2 mm
r_s = 27/20 = 1.35
Rearranging Eq. (13.22) in text, $D_m = r_{sd}^3 t_dD_d/t_m$ = (1.35)^2(2)(20)/(0.40) = **182.25 mm**

13.26 A rotational molding operation is to be used to mold a hollow playing ball out of polypropylene. The ball will be 1.25 ft in diameter and its wall thickness should be 3/32 in. What weight of PP powder should be loaded into the mold in order to meet these specifications? The specific gravity of the PP grade is 0.90, and the density of water is 62.4 lb/ft^3.

Solution: Density ρ = specific gravity of polymer x ρ_{water} = 0.90(62.4 lb/ft^3) = 56.2 lb/ft^3

19 BULK DEFORMATION PROCESSES IN METALWORKING

Review Questions

19.1 What are the reasons why the bulk deformation processes are important commercially and technologically?

Answer. Reasons why the bulk deformation processes are important include the following: (1) they are capable of significant shape change when hot working is used, (2) they have a positive effect on part strength when cold working is used, and (3) most of the processes produce little material waste; some are net shape processes.

19.2 Name the four basic bulk deformation processes.

Answer. The four basic bulk deformation processes are (a) rolling, (2) forging, (3) extrusion, and (4) wire and bar drawing.

19.3 What is rolling in the context of the bulk deformation processes?

Answer. Rolling is a deformation process in which the thickness of the workpiece is reduced by compressive forces exerted by two opposing rolls. The rolls rotate, thus pulling and simultaneously squeezing the workpiece between them.

19.4 In rolling of steel, what are the differences between a bloom, a slab, and a billet?

Answer. A bloom is a rolled steel workpiece with a square cross section of about 150 mm by 150 mm. The starting work unit for a bloom is an ingot heated in a soaking pit. A slab is rolled from an ingot or a bloom and has a rectangular cross section of about 250 mm by 40 mm. A billet is rolled from a bloom and has a square cross section of about 40 mm by 40 mm.

19.5 List some of the products produced on a rolling mill.

Answer. Rolled products include flat sheet and plate stock, round bar and rod stock, rails, structural shapes such as I-beams and channels.

19.6 What is draft in a rolling operation?

Answer. Draft is the difference between the starting thickness and the final thickness as the workpiece passes between the two opposing rolls.

19.7 What is sticking in a hot rolling operation?

Answer. Sticking is a condition in hot rolling in which the surface of the workpiece adheres to the rolls as the piece passes between the rolls, causing severe deformation of the metal below the surface in order to allow passage through the roll gap.

19.8 Identify some of the ways in which force in flat rolling can be reduced.

Answer. Ways to reduce force in flat rolling include (1) use hot rolling, (2) reduce draft in each pass, and (3) use smaller diameter rolls.

19.9 What is a two-high rolling mill?

Answer. A two-high rolling mill consists of two opposing rolls between which the work is compressed.

19.10 What is a reversing mill in rolling?

F_c = 101 cos(31 - 6)/cos(32.5 + 31.0 – 6) = 170 lb.
$HP_c = F_c v$/33,000 = 170(700)/33,000 = **3.61 hp.**

(b) R_{MR} = 700 x 12(0.0075)(0.075) = 11.3 in^3/min
$HP_u = HP_c / R_{MR}$ = 3.61/11.3 = **0.319 hp/(in^3/min)**

(c) Correction factor = 0.85 from Fig. 21.14 to account for the fact that f = 0.015 in/rev instead of 0.010 in/rev. Taking this correction factor into account, HP_u = 0.375/0.85 = **0.441 hp/(in^3/min)** as it would appear in Table 21.2 for a feed (t_o) = 0.010 in/rev.

21.31 In a turning operation on an aluminum alloy workpiece, the feed = 0.020 in/rev, and depth of cut = 0.250 in. The motor horsepower of the lathe is 20 hp and it has a mechanical efficiency = 92%. The unit horsepower value = 0.25 hp/(in^3/min) for this aluminum grade. What is the maximum cutting speed that can be used on this job?

Solution: From Table 21.3, HP_u = 0.25 hp/(in^3/min) for aluminum. Since feed is greater than 0.010 in/rev in the table, a correction factor must be applied from Figure 21.14. For f = 0.020 in/rev = t_o, correction factor = 0.9.
$HP_c = HP_u$ x R_{MR}, $HP_g = HP_c/E$
$R_{MR} = vfd$ = 12v(.020)(0.250) = 0.06 v in^3/min
HP_c = 0.9(0.25)(0.06 v) = 0.0135 v hp
HP_g = 0.0135 v /0.92 = 0.014674 v = 20 hp
v = 20/0.014674 = 1363 ft/min

Cutting Temperature

21.32 Orthogonal cutting is performed on a metal whose mass specific heat = 1.0 J/g-C, density = 2.9 g/cm^3, and thermal diffusivity = 0.8 cm^2/s. The cutting speed is 4.5 m/s, uncut chip thickness is 0.25 mm, and width of cut is 2.2 mm. The cutting force is measured at 1170 N. Using Cook's equation, determine the cutting temperature if the ambient temperature = 22°C.

Solution: ρC = (2.9 g/cm^3)(1.0 J/g-°C) = 2.90 J/cm^3-°C = (2.90x10^{-3}) J/mm^3-°C
K = 0.8 cm^2/s = 80 mm^2/s
$U = F_c v/R_{MR}$ = 1170 N x 4.5 m/s/(4500 mm/s x 0.25 mm x 2.2 mm) = 2.127 N-m/mm^3
$T = 0.4U/(\rho C)$ x $(vt_o/K)^{0.333}$
T = 22 + (0.4 x 2.127 N-m/mm^3/(2.90x10^{-3}) J/mm^3-C) [4500 mm/s x 0.25 mm/80 mm^2/s]$^{0.333}$
T = 22 + (0.2934 x 10^3 C)(14.06)$^{.333}$ = 22 + 293.4(2.41) = 22° + 707° = **729°C**

21.33 Consider a turning operation performed on steel whose hardness = 225 HB at a speed = 3.0 m/s, feed = 0.25 mm, and depth = 4.0 mm. Using values of thermal properties found in the tables and definitions of Section 4.1 and the appropriate specific energy value from Table 21.2, compute an estimate of cutting temperature using the Cook equation. Assume ambient temperature = 20°C.

Solution: From Table 21.2, U = 2.2 N-m/mm^3 = 2.2 J/mm^3
From Table 4.1, ρ = 7.87 g/cm^3 = 7.87(10^{-3}) g/mm^3
From Table 4.1, C = 0.11 Cal/g-°C. From note "a" at the bottom of the table, 1 cal = 4.186 J.
Thus, C = 0.11(4.186) = 0.460 J/ g-°C
ρC = (7.87 g/cm^3)(0.46 J/g-°C) = 3.62(10^{-3}) J/mm^3-°C
From Table 4.2, thermal conductivity k = 0.046 J/s-mm-°C
From Eq. (4.3), thermal diffusivity $K = k/\rho C$
K = 0.046 J/s-mm-°C /[(7.87 x 10^{-3} g/mm^3)(0.46 J/g-°C)] = 12.7 mm^2/s
Using Cook's equation, $t_o = f$ = 0.25 mm
T = (0.4(2.2)/3.62(10^{-3}))[3(10^3)(0.25)/12.7]$^{0.333}$ = 0.2428(10^3)(59.06)$^{0.333}$
= 242.8(3.89) = 944.4 C°
Final temperature, taking ambient temperature in account T = 20 + 944 = **964°C**

sin I = 7.0/235.62 = 0.0297 **I = 1.70°**

25.9 In a certain centerless grinding operation, the grinding wheel diameter = 8.5 in, and the regulating wheel diameter = 5.0 in. The grinding wheel rotates at 3500 rev/min and the regulating wheel rotates at 150 rev/min. The inclination angle of the regulating wheel = 3°. Determine the throughfeed rate of cylindrical workparts that have the following dimensions: diameter = 1.25 in and length = 8.0 in.

Solution: From Eq. (25.11), $f_r = \pi D_r N_r \sin I = \pi(5.0)(150) \sin 3° = 123.33$ in/min
Parts feed at (8.0 in/part)/(123.33 in/min) = 0.0649 min/part = 3.9 sec/part
Throughfeed rate = 1/0.0649 = **15.4 parts per min**

25.10 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, 35 mm in width, 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 workspeed 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 x 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 x 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.

25.11 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 Eq. (25.8). 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.

25.12 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

41.5 A certain piece of production equipment is used to produce various components for an assembled product. To keep in-process inventories low, it is desired to produce the components in batch sizes of 150 units. Demand for each product is 2500 units per year. Production downtime costs an estimated \$200/hr. All of the components made on the equipment are of approximately equal unit cost, which is \$9.00. Holding cost rate = 30%/yr. In how many minutes must the changeover between batches be completed in order for 150 units to be the economic order quantity?

Solution: $EOQ = (2D_aC_{su}/C_h)^{0.5}$
$(EOQ)^2 = 2D_aC_{dt}T_{su}/hC_p$
$T_{su} = hC_p(EOQ)^2/2D_a\,C_{dt}$ = 0.3(9.00)(150)^2/(2 x 2500 x 200) = **0.06075 hr = 3.65 min.**

41.6 Current setup time on a certain machine is 3.0 hr. Cost of downtime on this machine is estimated at \$200/hr. Annual holding cost per part made on the equipment, C_h = \$1.00. Annual demand for the part is 15,000 units. Determine (a) *EOQ* and (b) total inventory costs for this data. Also, determine (c) *EOQ* and (d) total inventory costs, if the changeover time could be reduced to six minutes.

Solution: (a) $EOQ = (2D_aC_{su}/C_h)^{0.5}$ = (2 x 15,000 x 3.00 x 200/1.00)$^{0.5}$ = **4243 pc**

(b) $TIC = C_hQ/2 + C_{su}D_a/Q$ = 1.00(4243/2) + 3.00 x 200(15,000/4243)
= 2121.50 + 2121.14 = **\$4242.64**

(c) If T_{su} = 6 min = 0.1 hr, $C_{su} = C_{dt}T_{su}$ = 200(0.1) = \$20.
EOQ = (2 x 15,000 x 20/1.00)$^{0.5}$ = **775 pc**

(d) *TIC* = 1.00(775/2) + 20(15,000/775) = 387.50 + 387.10 = **\$774.60**

41.7 The two-bin approach is used to control inventory for a particular low-cost component. Each bin holds 1200 units. The annual usage of the component is 45,000 units. Cost to order the component is around \$70. (a) What is the imputed holding cost per unit for this data? (b) If the actual annual holding cost per unit is only 7 cents, what lot size should be ordered? (c) How much more is the current two-bin approach costing the company annually, compared to the economic order quantity?

Solution: (a) $EOQ = (2D_aC_{su}/C_h)^{0.5}$
1200 = (2 x 45,000 x 70/C_h)$^{0.5}$
C_h = 2 x 45,000 x 70/1200^2 = \$4.38 annually

(b) Given C_h = \$0.07, *EOQ* = (2 x 45,000 x 70/0.07)$^{0.5}$ = 9486.83 $\rightarrow$ **9487 pc**

(c) For the two-bin approach in which Q = 1200, TIC = 0.07(1200/2) + 70(45,000/1200)
= 42 + 2625 = \$2667.00
For the *EOQ* = 9487, *TIC* = 0.07(9487/2) + 70(45,000/9487) = 332.05 + 332.03 = \$664.08
Additional cost = 2667.00 – 664.08 = **\$2002.92**

Material Requirements Planning

41.8 Quantity requirements are to be planned for component C2 in product P1. Required deliveries for P1 are given in Table 41.1. Ordering, manufacturing, and assembly lead times are as follows: for P1 and C2, the lead time is one week; and for S1 and M2, the lead time is two weeks. Given the product structure in Figure 41.4, determine the time-phased requirements for M2, C2, and S1 to meet the master schedule for P1. Assume no common use items and all on-hand inventories and scheduled receipts are zero. Use a format similar to Table 41.2 and develop a spreadsheet calculator to solve. Ignore demand for P1 beyond period 10.

Solution:

Period	1	2	3	4	5	6	7	8	9	10
P1 Requirements								50	75	100
Order Release							50	75	100	