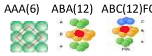
Chapter 1: Crystalline solids

Unit cell: Single basic structural repeat unit that, when duplicated and translated, reproduces the entire crystal structure.

Coordination number: (of an atom) is the number of nearest neighbouring atoms touching it.

AAA(6) ABA(12) ABC(12)FCC

close packed: 

BCC: 8(non-close packed)

Number of atoms per unit Cell: how many unit-cell has this atom?

Simple: 1

BCC: 1 + 8(1/8) = 2

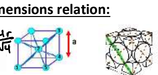
FCC: 8(1/8) + 6(1/2) = 4

$N_{atom\ per\ u/c} = \sum n_i * part\ of\ atom_i\ in\ u/c$

Atomic radius & u/c dimensions relation:

BCC: $a = \frac{4r}{\sqrt{3}}$ SC: a= $\frac{4r}{\sqrt{4}}$

FCC: $a = \frac{4r}{\sqrt{2}}$



Atomic Packing Factor: how efficient the atoms are packed in a crystal strc.

$APF = \frac{Total\ volume\ of\ atoms\ in\ a\ unit\ cell, V_s}{Total\ volume\ of\ unit\ cell, V_c}$

FCC: face centre = ½, corner = 1/8 atm

BCC: centre = 1, corner = 1/8 atom

Density of unit cell:

$Density\ of\ unit\ cell, \rho_c = \frac{n \times A_m}{N_A \times V_c}$

n = no. atoms per unit cell

A_m= atomic mass of atom

N_A = Avogadro's Number

V_c = Volume of Unit Cell

Single Crystal vs Polycrystalline Solids

Perfect 3-D periodic arrangement of atoms throughout the entire structure All unit cells interlock in the same way and have the same crystallographic orientation Varying degree of anisotropy depending on symmetry of crystal structure (the anisotropy refers to direction dependent material properties)	Polycrystalline are solids made from many small crystals or grains Grain boundaries are formed where crystals meet Tend to be isotropic due to random crystallographic orientations of individual grains (the isotropy refers to direction-independent properties)

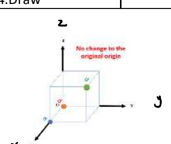
Chapter 2: Crystallography

Point Coordinates: Location of atom in a u/c given by its coordinates

Crystallographic Directions: vector connecting coordinate origin and a specific point in a u/c **[u v w]**

Selection of origin: if number is negative [$\bar{1}$], shift origin to "1".

Indices given	Direction Drawn
1.Select Origin 2.Reduce maximum number to 1 3.Locate vector direction from new origin 4.Draw	1.Select Origin (start of vector) 2.Determine coord of endpoint of vector from origin 3.Reduce values to **whole** numbers 4.Place "[ ]"



Families of directions in u/c: Set of directions that are crystallographically identical **<u v w>**

- Important because members of the same crystallographic direction will have the same properties i.e packing density & physical properties

- Directions must be unique i.e not parallel to each other

- family eg: <110>

$[110][\bar{1}10][1\bar{1}0][\bar{1}\bar{1}0]$

$[101][\bar{1}01][10\bar{1}][\bar{1}0\bar{1}]$

$[011][0\bar{1}1][01\bar{1}][0\bar{1}\bar{1}]$

Crystallographic Planes: set of parallel and equally spaced planes that pass-through atom centres (no centre must be situated between planes) **(h k l)**

- distance between successive planes depends on their direction in relation to the arrangement of atomic centres

- planes are important for mechanical deformation of metals (anisotropy & isotropy) & transportation or electrons/ conductivity

Miller indices given	Drawn plane
1. Select origin 2. Reciprocate indices **1/0 = ∞ = parallel** 3. Reciprocated indices is the intercept 4. Mark intercept along x-y-z axes 5. Connect intercepts to get plane (Note importance of parallelism)	1. Choose closest corner (**plane cannot touch origin**) 2. Select corner as origin 3. Find intercepts with x-y-z axis 4. take reciprocals of intercepts 5. reduce multiples, eliminate fractions & add bar for negative 6. Round brackets

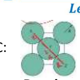
Family of planes: members of planes in the same unit crystal that are crystallographically equivalent **{ h k l }**

- Same packing density, same atomic environment, same mechanical & physical properties i.e {100}

$(100)(\bar{1}00)(010)(0\bar{1}0)(001)(00\bar{1})$ basically having one "1" makes it the same family

Linear Density: determines directional equivalence of a single crystal. Vector MUST cut through the middle of the atom

$LD = \frac{No.\ of\ atoms\ centered\ on\ directional\ vector}{Length\ of\ directional\ vector}$

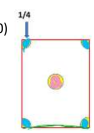
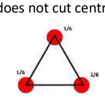
FCC: 

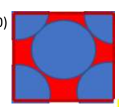
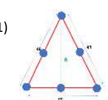
Planar Density

$PD = \frac{No.\ of\ atoms\ centered\ on\ a\ plane}{Area\ of\ plane}$

Plane must cut through CENTRE of atom

Only AREA of the atom IN THE PLANE is considered

BCC: (110)  (111) does not cut centre atm 

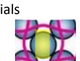
FCC: (100)  (111) 

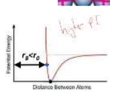
Atoms in plane = 1/6 (3) + ½(3) = 2

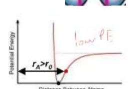
Chapter 3: Defects

Point, Line, Interfacial, bulk/volume defects

Point defect: Vacancies & self-interstitials

Vacancy:  Self-interstitials: 





Impurity: Substitutional Interstitial

Energy-cost of crystalline defects: Most crystalline defects create strain, distorts lattice -> Increase energy of system (G). System will tend to reach an equilibrium structural state, minimising G

G = H (enthalpy) – TS (entropy)

Entropy – energy associated with creation of states

Enthalpy – energy-cost to break atomic bonds

T = Constant $\Delta G = \Delta H - T\Delta S$

Arrhenius Law: Vacancy concentration,

$$\frac{n}{N} = \exp\left(-\frac{Q_v}{kT}\right)$$

n: number of defects (vacancies)

N: number of atomic sites

Q_v: activation energy for vacancy formation [J/mol.] or [eV/atom]

k: Boltzmann's constant 1.38×10^{-23} [J/atom/K] or 8.62×10^{-5} [eV/atom/K]

Formation of point defects:

Annealing & Quenching – Kinetically trapping defects

Irradiation by high energy particles

Ion implantation – high energy ions implemented in material

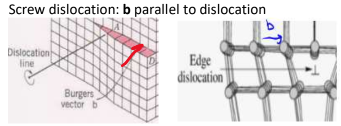
Cold working – irreversible mechanical deformation at low temperatures

Dislocations

Burger's vector, **b**: Magnitude and direction of the lattice distortion of a dislocation

Edge dislocation: **b** perpendicular to the dislocation

Screw dislocation: **b** parallel to dislocation



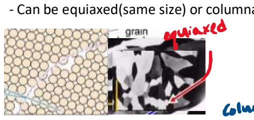
Polycrystalline Materials

Grain Boundaries: Regions between crystals

- Transition line from lattice to lattice
- slightly disordered
- low density of atomic packing in grain boundaries

High mobility, diffusivity & chemical reactivity

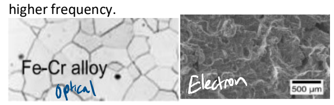
- Can be equiaxed(same size) or columnar (elongated)



Microscopy

Optical microscopy – 2000X magnification. Boundaries evealed as darklines, change in crystal orientations can be observed. Can use polarized light to increase contrast and to observed transparent samples

Electron Microscopy – 10^{-7}m. Higher resolution, higher frequency.



Chapter 4: Phase Diagrams

Solubility limit – max conc. For a single phase solution to exist

Equilibrium phase diagrams – all phase diagrams are computed when system is at thermodynamic equilibrium (G min) i.e do not change with time, T constant

Solute – Minority component in an alloy

Solvent – Majority component in an alloy

Hume-Rothery rules for complete solid solutions

1) Atomic Size factor – Difference in atomic radii between atoms less than ±15%

2) Crystal Structure – crystal structures formed by both atoms must be of the same type, FCC etc.

3) Electronegativity – Both components' atoms must be similar, if not ions will be formed

4) Valency – combining capacity of both elements must be similar

More than 2 elements can form a solid solution, including ions (of similar charge)

Isomorphous binary phase diagram

Simplest possible diagram

2 independent variables T & conc.) P = 1atm

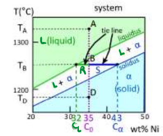
Composition of that phase

i.e., B: both α & L present

C_L=32% (trace left)

C_α= 43%(trace right)

A: only L C: only α



Phase weight fraction

B: Opposite! i.e for weight fraction of liquid, take

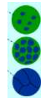
S = C_α- C_0 (line to solidus)

$W_L = \frac{S}{R+S}$ $W_\alpha = \frac{R}{R+S}$

Solidification during cooling: Trace conc line down as temperature decreases.

Faster rate of cooling – cored structure

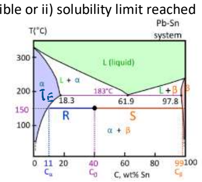
Slower rate of cooling – Equilibrium struc



Binary Eutetic System

- Above the solubility limit, a new phase is formed (β)
- B has different compositions with α (both solutions)
- May have different crystal structure
- multiple phases coexist when:

i) immiscible or ii) solubility limit reached



Contains 3 single phase regions

T_E: No liquid below T_E(eutectic temperature)

C_E: Composition at temperature T_E

Weight compositions: Similar to isomorphous

Find the point with T & C. Extend to the right & left to find the phases present. Calculate using the "opposite" analogy.

Development of eutectic alloy

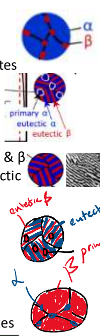
For $2 < C_0 < 18.3$: Formation of polycrystalline with α grains β-phase particles/precipitates

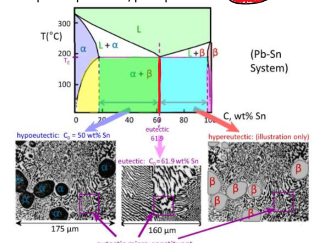
For $18.3 < C_0 < C_E$: Formation of **near-eutectic** alloys

For $C_0 = C_E$: Direct formation of α & β Results in eutectic alloy, with eutectic microstructure (lamellar)

For $C_E < C_0 < 97.8$: Formation of near-eutectic alloys

For $97.8 < C_0 < 99$:, Formation of polycrystalline with β grains α-phase particles/precipitates





Treat intermetallic compounds as two different phase diagrams that are conjoined

Eutectic: Liquid $\underset{heat}{\overset{cool}{\rightleftharpoons}}$ solid1 + solid2

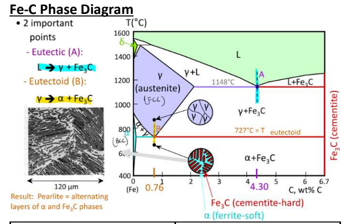
Eutectoid : Solid1 $\underset{heat}{\overset{cool}{\rightleftharpoons}}$ solid2 + solid3 – Solid state phase transformation

Peritectic: Liquid + solid1 $\underset{heat}{\overset{cool}{\rightleftharpoons}}$ solid2

Phase diagram uses: explains what processing to use to control composition,size and arrangement of phases in a certain system

We control the microstructure of the alloy through such processes to achieve the alloy properties that we want

Fe-C Phase Diagram



Pearlite - The combination of cemenite and ferrite makes pearlite a tough phase - ferrite is soft and ductile, while cementite is hard and brittle - For this reason, pearlite is ideal of blade BODY	Martensite - Martensite originates from rapid cooling/quenching of austenite - As such, it is a non-equilibrium phase and thus does not show up in the C-Fe phase diagram. - Martensite is the strongest and hardest phase that is available in the C-FE system - Because of its strenght, Martensite is ideal for the blade cutting edge - Cementite decomposes to ferrite + graphite

Differential quenching is the quenching process of cooling down a single piece of metal at different rates, using different thickness of clay layers to control the rate the metal cools.

Metal alloys: Ferrous – iron based, non-ferrous - others

Ferrous: High densities, low electrical conductivities, poor corrosion resistance

Types of iron alloys:

Cast iron – more than 2.1 wt% (usually 3-4.5). Low Melting point, generally brittle.

Chapter 5: Mechanical properties of materials

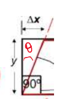
Engineering stress A_o is the original area before load

$\sigma = \frac{F_t}{A_o} = \frac{N}{m^2}$ $\tau = \frac{F_s}{A_o}$

σ < 0 => compression

Engineering Strain

Tensile strain: $e = \frac{\delta}{L_o}$ Shear Strain: $\gamma = \Delta x/y = \tan\theta$



Stress-strain graph properties

Young's Modulus - $\frac{\partial\sigma}{\partial\varepsilon}$ slope of elasticity region

Yield Strength - σ_y @0.2% **plastic** strain

U Tensile Strength – Peak of plastic curve

Ductility(%EL) – $\frac{Final\ length - Original\ length}{Original\ length} * 100\%$

Area Reduction (%RA) - $\frac{Final\ Area - Original\ Area}{Original\ Area} * 100\%$

Toughness – Area under curve -> Energy required

Elastic Strain energy/Resilience: Ability to store energy through deformation. (Linear elastic) Equals to area under stress-strain curve (elastic region)

$$U_r = \frac{1}{2}\sigma\varepsilon = \frac{E\varepsilon^2}{2} = \frac{\sigma^2}{2E}$$

Yield Strength: Stress where noticable plastic deformation has occurred (0.2% plastic strain)

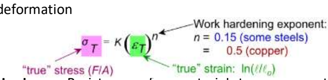
Toughness: Energy required to break a unit volume of material = area under curve till failure

True Stress & Strain: Area change when stretched

$\sigma_T = F/A_i$ $\epsilon_T = \ln(\ell_i/\ell_o)$ $\sigma_T = \sigma(1+e)$ $\varepsilon_T = \ln(1+e)$

e = engineering strain

Work/strain Hardening: Increase in σ_y due to plastic deformation

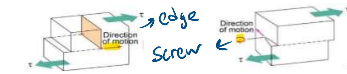


Hardness: Resistance of a material to permanent indentation. Hardness = Pmax/Area

Chapter 6: Dislocations & Strengthening mechanisms

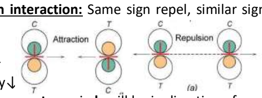
Plastic deformation occurs by slip – edge dislocation sides over adjacent planes

Dislocation motion: Moves along slip plane in a slip direction(same as **b**) perpendicular to dislocation line. Dislocation requires successive bumping of half plane of atoms. Bond are broken and remade in succession.



Dislocations are defects that increase the energy of the system proportional to b^2(burgers vector)

Dislocation interaction: Same sign repel, similar sign attract and cancel each other out (energy↓)



LD & Burgers vector: min **b** will be in direction of max linear density. Atoms are closer, require less energy to move along atoms -> energy required lower.

FCC: min **b** along u/c face BCC: min **b** across diagonal

Slip: Slip plane – highest PD, slip direction – highest LD

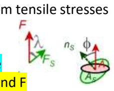
Stress & dislocation motion: τ_R – from tensile stresses

1.Resolve tensile stress & shear area

$\tau_R = \sigma\cos\lambda\cos\phi$

λ angle between slip plane and force

ϕ angle between slip plane normal and F



τ_R max = $\sigma/2$,both angle 45◦

Non-metals – ionic(need to avoid similar signed)

Covalent(little slip systems – angular bonds & complex)

Ceramics – few slip systems, break before plastic def.

Strengthening

Grain boundary strengthening: T<0.5T_m, boundaries act as barriers to dislocation motion. Higher energy required for change in direction.

Smaller grain size, more barriers to slip, higher stress required, higher str. $\sigma_y = \sigma_0 + kD^{-0.5}$

Solid Solution ": addition of solute to generate a strain field to resist dislocation – act as barriers to dislocation. Smaller atoms tend to conc at regions of compressive strains, causing cancellation of dislocation compressive strains, reducing disl mobility.

Cold work: σ_y↑ Tensile Str↑ Ductility ↓ (trade off)

Dislocations multiply and entangle, causing dislocation motion to be more difficult. CW occurs at Room Temp.

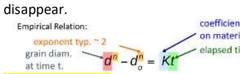
$\%CW = \frac{A_o - A_d}{A_o} \times 100$

Annealing: CW uses intermittent annealing, restore ductility. Nullifies effect of CW (heating)

1. Recovery: diffusion: atoms move to regions of tension and annihilate dislocations to form perf plane. Climbing: dislocations climb into vacant slots after diffusion to reduce dislocation density

2. Recrystallisation: new grains form to have low dislocation densities, smaller in size and replace parent grains.

3. Grain Growth: big grains grow, small grains disappear.



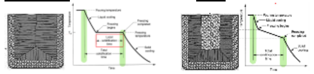
$0.3T_m < T_R < 0.6T_m$ T_R: temp where recrystallization finishes in 1 hr. Depends on:

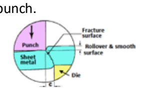
%CW - T_R↑ as CW↑ & Purity: T_R↓ as purity↑

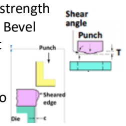
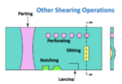
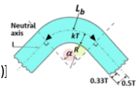
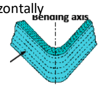
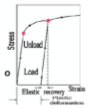
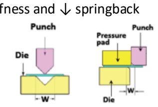
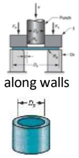
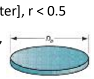
Hot Working: deformations at ABOVE T_R

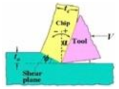
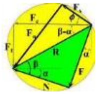
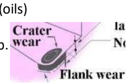
Cold Working: deformations BELOW T_R

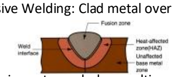
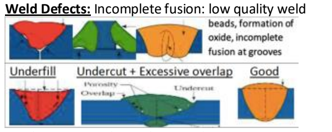
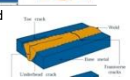
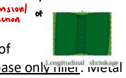
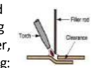
Done by: Ho Min Han

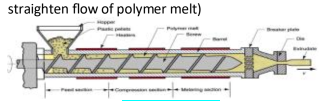
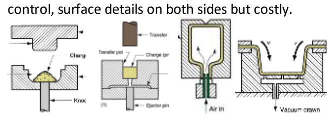
Chapter6: Overview Manufacturing
Metal Casting: casting; Metal Forming: extrusion; Metal Machining: drilling, milling; Metal Joining: welding
1.Additive Manufacturing: increase weight(3d printing)
2.Subtractive Manufacturing: decrease weight(Milling)
3.Formative Manufacturing: no weight change(Casting)
NET shape process: Little of no waste and no machining is required
Good environmentally conscious manufacturing: Proper choice of materials, design products that minimize environmental impact. Manufacturing processes that are environmentally friendly
Dimensions: Part sizes desired by the designer if the part could be made with no errors or variations.
Tolerance: Total amount by which a specific dimension is permitted to vary
Tolerance = positive tolerance – (negative tolerance)
ACCURACY: True value of the quantity, quality/ random error; **PRECISION:** degree of repeatability, systematic error
Apparatus: micrometer – diameter, vernier calliper, bevel protractor, sine bar (sin Angle = Height/Length)
Surface Roughness: Average vertical deviation from nominal surface over a specified surface length
$R_a = \sum_{i=1}^{n}\frac{|y_i|}{n} = \frac{y_1+y_2+y_3}{n}$ (ABS VALUE, no sign)
1. Roughness: lack of precision,small varia. ard nominal
2. Waviness: lack of accuracy: large varia. of the value
Chapter7: Metal Casting
PROS: Create complex geometries for both external and internal shapes. Large parts, suited for mass productions. (Near) Net Shape.
CONS: Environmental problems. Safety hazards to workers, poor dimensional accuracy and surface finish, limitations on mech. properties
Terminology - Cope (Upper half of mold), Drag (Bottom half), Flask (Box contains the mold halves), Parting Line, Core (Used for interior geometry), Down Sprue (a runner towards the main cavity), Pouring cup, Riser (Compensate for shrinkage & freeze later), Gate
Flow Velocity V = $\sqrt{2gh}$,
Fluidity-how fast to fill the cavity
High viscosity = Low Fluidity (Spiral test)
Continuity Law Q =A1V1 = A2V2 (cm³/s)
Reynolds number Re = $\left(\frac{D\nu\rho}{\mu}\right)^2$, Re < 2,000 (Laminar), Re > 20,000 (Turbulent)
Mold Filling T_{MF} = Vol/Q (cm³)
Chvorinov's (Solidification) $T_{TS} = C_m\left(\frac{V, Vol. of\ Casting}{S, Area\ of\ Casting}\right)^2$
[Entire Surface Area, C_m: Types of metal, density, temp, heat capacity] Net shape: complex features w/o add. work
Pure metal   Alloy

Shrinkage: Ori. Length = Mold length (1-x); E.g., Cast Iron high in C > (freezing stage) expansion and counteracts volumetric decreases associated with phase change
Pouring of Metal
Pouring Temp: Raise temp to M.P, latent heat of fusion, raise temp. to desired pouring temp.
Rate: Slow, metal freeze before filling cavity. Fast, Turbulence (cavity + degrade casting quality), irregular flow. Tapered Sprue - Prevents aspiration of air
Riser Design: Time for riser to solidify > Time for rest of casting to solidify - > Maximize V/A (longer T_{TS})
Casting quality: Fluidity (too hard), Pouring temp (too low), Velocity (too slow), Improper design, turbulence, shrinkage
Casting General Defects:
Misrun: Casting solidified before completely filling mold cavity.
Cold Shut: Two position of metal flow together but there is a lack of fusion due to premature freezing.
Cold Shot: Metal splatters during pouring lading to formation of globules, which become entrapped in the casting.
Shrinkage Cavity: Depression in the surface caused by solidification shrinkage that restricts molten metal to freeze.

Microporosity: Small voids distributed throughout the casting caused by localized solidification shrinkage of final molten metal within dendritic structure.
Hot Tears/Cracks: Casting restrained from contraction because of mold from final stages of solidification or early stage of cooling
Achieving Directional Solidification: CHILLS (internal or external heat sinks that cause rapid freezing in certain regions of the casting
Product Design Considerations: Geometric Simplicity /Corners on the casting / Section thickness / Draft angle (taper) /eliminate the need of core / Dimensional tolerance & surface finish / Machining allowances.
Expendable mold casting: Investment Casting, Sand casting.
Sand Casting: Most widely used, nearly all alloys can be used, varying sizes can be done, high quantities produced
Investment Casting: 1. Wax pattern is produced.
2.Patterns attached to sprue to form pattern tree.
3. Tree is coated with layer of refractory material
4. Full mold is formed by covering coated tree with sufficient refractory material to make it rigid.
5. Mold held inverted position and heated to melt wax andpermit it to leak out of the cavity.
6. Mold preheated to high temp, molten poured & solidify. 7. Mold is broken away from the finished casting and parts are separated from the sprue
PROS: Net shape process, wax can be reused. Close dimensional control, good surface finish.
CONS: Expensive and many steps required.
Permanent Mold Casting (aluminum, magnesium, iron) Mold is preheated & coated for lubrication & heat dissipation. Cores (if used) are inserted, and mold is closed. Molten metal poured into mold & solidifies.
PROS: Dimensional control and surface finish. Rapid solidification results in finer grain structure so casting is stronger. Mold can be reused. Economical for large production. Thin sections possible.
CONS: Generally limited to metals of lower melting point, simpler part geometries compared to sand casting because need to open mold. Mold expensive.
Die Casting-high pressure to force metal into die cavity
Hot chamber die casting: Casting metals: zinc, tin, lead,and magnesium | Low MP | Heated Chamber
Steps: With the die closed and plunger withdrawn, molten metal flows into chamber. Plunger force metal flow to die under constant pressure. Withdraw ram; open die, eject parts
Cold Chamber die casting: Casting metals: aluminum, brass, and magnesium alloys, Unheated Chamber
Steps: With the die closed and ram withdrawn, molten metal is ladled (thus extra time) into chamber. Ram forces metal to flow into die, maintaining pressure during cooling and solidification. Withdraw ram; open die, eject part
PROS: Economic for large production, good accuracy, thin section possible, rapid cooling – small gain size & good strength of the cast product.
CONS: Limited to metal with low melting point, part geometry limited for removal from the die.
Chapter 8: Metal Forming
Sheet metal working: Thickness of sheet metal = 0.4mm to 6mm, larger=plate
Rolling: Hot rolling: above T_{recrys} ;Cold rolling: below (better surface finish as no scale formation, better tolerance and better mech properties)
2/3-high roll: used for hot rolling (3:reverse direction)
4-high: smaller diameter rolls, lower rolling force, reduce spreading. Usually cold rolling. (planetary)
Rotary tube piercing – hot-working process for long thick-walled seamless pipes. Round bar subjected to radial compressive forces and develops tensile stresses at its centre-> cavity. Internal mandrel expands hole and defines bore of tube
Sheet metal forming:
PROS sheet metal: Strong, dimensionally accurate, good surface finish, low cost, mass production
Blanking & punching: shearing operation
Rollover: Depression made by punch.
Burnish: Smooth region due to penetration.


Fracture zone: Quite rough surface due to fracture.
Burr: Sharp corner edge due to elongation of metal.
Shearing: Separate large sheets
Blanking: Cut part perimeters from sheet metal.
Punching: Make holes. Clearance: usually 2-10% T
Clearance: As c↑, sheet pulled into clearance zone rather than sheared, gives rougher edges, burr height↑, punch force↓, die wear↓ c = at, a = allowance, t = thickness
(Blanking)Punch and Die Diameter/Round Blank D_b:
Die diameter = D_b ; Punch Diameter = D_b – 2c
(Punching) Punch and Die Diameter/Round Hole D_H:
Punch Diameter = D_h ; Die Diameter = D_h + 2c
Angular clearance: Allow blank to drop (0.25 to 1.5)°
Max Punching Force: F = 0.7(UTS)tL = StL , S = Shear Strength, t = sheet thickness, L = length of shear (perimeter), UTS = ultimate tensile strength
Changing die reduces cutting force: Bevel shear i.e where the centre cuts first followed by outside.

Other Shearing operations:
Shaving – extra material removed to get straight edge (small clearance between punch & die)
Fine Blanking – Blanking w cushion below + pressure pads, c ≤ 1 % T, smooth/square edge, good dimensional tolerance

Bending
Bend Allowance, L_b:
$L_b = 2\pi\frac{\alpha}{360}(R + kT)$
$\alpha = 180 - \alpha'$[bend angle (degree)]
R = bend radius
k = constant (0.33 ~ 0.5)   R<2T, k= 0.33 ; R> 2T, k=0.5
T = sheet metal thickness

Minimum bend radius: eng. strain $e = \frac{1}{\frac{2R}{T}+1}$
As R/T ↓, tensile strain at outer fibre ↑, causing cracks
Cracks first occur -> min. bend radius. Usually expressed in terms of T.
Anisotropy: Diff. behavior in diff directions, acquired during sheet metal processing (rolling)
1. Preferred grain direction: caused by compression od equiaxed grains, boundaries align horizontally (preference in grain orientation)
2. Mechanical fibering: alignment of impurities, inclusions and voids during deformation -> bending should be done perpendicular to rolling direction

Springback: Elastic recovery after load removed, bend angle ↓, bend radius ↑
$\frac{R_i}{R_f} = 4\left(\frac{R_i Y}{ET}\right)^3 - 3\left(\frac{R_i Y}{ET}\right) + 1$
E: elastics modulus   Y: Yield strength

Compensation: Overbending, bottoming (high compressive pressure cause plastics deformation to reduce thickness at bend area) & stretch bending (sheet stretched past yield stress then bent). Including Ribs or darts can increase stiffness and ↓ springback
Bending operation:
V-Die: Simple, Cheap, acute to obtuse
Wiping-Die: Complicated, high quality, precise

Bending Force: P = $\frac{k(UTS)LT^2}{W}$ k=1.33   k=0.33
L=part width in bend axis*; t: sheet thickness; W: die opening
Deep Drawing: Clearance = 1.1 t
1. Blank holder holds sheet metal in place.
2. Punch moves down, bend sheet metal
3. Straighten to form cup wall, high tension along walls and high compression in flange, cause tearing and wrinkling respectively
*Force on B.Holder: too high -> tearing; too low -> wrinkles

Drawability: DR, reduction, thickness-diameter ratio
Drawing Ratio(DR) = $\frac{Blank\ Diameter, D_b}{Punch\ Diameter, D_p}$, if DR >2.0, not feasible
Reduction: $\frac{D_b - D_p}{D_b}$ [% reduction in diameter], r < 0.5
Thickness to diameter ratio: $\frac{t}{D_b} > 0.01$, $\frac{t}{D_b}$ ↓, tendency to wrinkle ↑


->If conditions are not met, redrawing is required, with annealing between each drawing.
Redrawing: Drawn cup faced UPWARDS on die
Reverse Drawing: Drawn cup faced DOWNWARDS on die, requires lesser force than redrawing
Blank Size: Initial blank Vol. = Final Vol. of the cup !!
Drawing Force: $F = \pi D_p t(TS)(\frac{D_b}{D_p} - 0.7)$
0.7 = accnts for friction
Blank holder Force:
$F_h = 0.015Y\pi\{D_b{}^2 - (D_p + 2.2t + 2R_d)^2\}$
F_h (N); Y (MPa); the rest (mm)
Drawing defects: wrinkling, tearing, earing(anistropy), surface scratches
Chapter 9: Metal Machining
PROS: Good dimensional accuracy and surface finish
CONS: Waste materials, takes a long time to shape
Cutting Models: Oblique(< 90deg) & Orthogonal(90°)
V = Cutting velocity
α = rake angle   *side view*:
ø = shear angle
t_o = undeformed thickness
t_c = chip thickness

Merchant Equation: assumed that ø adjusts itself to give minimum cutting force $\phi = 45° + \frac{\alpha}{2} - \frac{\beta}{2}$
(Use when given) β=friction angle
Cutting Force: R = $\sqrt{F_c{}^2 + F_t{}^2}$
Friction Coe.: $\mu = \frac{F}{N} = tan\beta$
Shear stress = $\frac{F_s}{A_s}$ (w = width of chip
$A_s = wt_o/\sin\phi$ NOT thickness)

Power & Material Removal Rate
Power = Force x Velocity (W.s)
U, Specific Energy = $\frac{Power}{MRR}$ (J/mm³)
Temperature: energy lost converted to heat => shear zone & tool chip interface
T↑: 1. (Cut.tool) Strength, hardness, wear resistance↓
2. Dimensional inaccuracies in w/p, thermal damage, fail easier (Workpiece) 3. Uneven temp. distort machine, difficult to control dimensions(machine tools)
Cutting fluid: Lubricant & coolant(oils)
Tool wear: flank (rubbing of tool & high temp.) & crater (high temp. & chemical affinity with w/p -> use coated with TiN, TiC)

Signs for replacement 1. Obvious tool wear 2. w/p surface finish gets worse 3. F_c ↑ 4. T↑ significantly
Taylor's tool life eqn: $VT^n = C$, V= cutting speed(m/min)
T = tool life(min), n= exponent (<1) ,C=constant
$VT^n d^x f^y = C$, d= depth of cut mm, f = feed mm/rev
Cutting too l material: 1. Hot hardness 2. Toughness 3. Thermal shock + Wear resistant 4. Chemically stable
Types of chips: 1. Continuous: Ductile material @ high speed, good surface finish, entangles tools [Change machining parameters or use chip breaker]
2. Discontinuous: Brittle, x w/stand high shear strain, Hard impurities, cutting force varies during cutting
3. Built-up edge: Layers of w/p deposited on tool. BUE↑, tool breaks. Some BUE will deposit in w/p surface, poor surface finish. BUE makes tool dull
4. Serrated:↓thermal conductivity, strength↓ w temp
Surface finish: Factors: chips types, feed mark left by cutting, vibration*
$R_a = \frac{f^2}{32R}$, $R_t = \frac{f^2}{8R}$(peak to valley), either↑, finish↓)
*1. forced: force from machine tool, 2. chattering: self-excited vibration from interaction of cutting process and machine tool. Starts from disturbance in cutting zone
Others: 1. Turning: MRR=dfV, depth of cut, d = $\frac{D_o - D_f}{2}$, V = πDN, N: rota. speed(rev/min), D = $\frac{D_o + D_f}{2}$, High MRR cuts at high f & d, then lower f & d for good surface finish 2. Cutting: MRR = wt_oV (mm³/s), w: width, t_o: Thickness 3. Drilling: MRR = $\frac{\pi D^2}{4} f N$, f,feed: (mm/rev), cutting time = $\frac{l, length\ cut}{fN}$, Power = torque (in Nm)* rot. speed (rad/s) 4. Milling: Conventional (upward) - max thickness at end of the cut, x affects tool life, chatter need clamp w/p + climb (downward) - max thickness at the start(bad), downward cutting force hold w/p in place(good), scales will cause dmg on cutter, high impact forces require rigid set up.

5. Grinding: dimensional accuracy and surface finish
Chapter 10: Metal Joining (Atomic Bonding)
Welding: 1. Fusion Welding (Arc, OFW, Laser): melts base metal, sometimes have filler metal (w/o – autogenous) 2. Solid State Welding (Ultra. Wire bonding): no melting of base metal, no filler is added, if heat used, temp. below melting point, no melting
Power: Power density (W/mm²)= P/A, Power within A, Unit energy for melting, U_m (J. mm³)= $kT_m{}^2$,
k = 3.33x10⁻⁶, T Melting Temp. in Kelvin
Heat Transfer: f_1: Heat received by w/p / total heat, f_2: Proportion of heat received by w/p used to melt
$H_w = U_m V$, V: Vol. of metal melted, $H_w = f_1 f_2 H$/ $f_1 f_2 EI$
H_w= heat for welding, H = Total heat, f_1: (arc weld. √) affected by welding, f_2: affected by thermal conductivity & welding (↑ thermal, rapid decrease in temp)
Energy balance (rate, t): Welding speed, v = $\frac{f_1 f_2 H_{Rate}}{U_m A_w}$
A_w= weld area, H_{Rate} = rate heat is generated
$H_W = U_m V \rightarrow HR_W = U_m(WVR)$
$H_W = f_1 f_2 H \rightarrow HR_W = f_1 f_2 HR = U_m A_w v$
Welding vol. rate: Wire.CSec. area*f, HR_w =IE, Rate of heat
Arc Welding: Use electric arc to heat metal
- Shielding: inert gas/flux prevent oxides and provide protective atm., stabilize arc, reduce spattering)
- Electrode coated w or contained in flux
- Electrodes: Consumables – filler metal (e.g. W.rods changed often; W. wire continuous feed, avoid interruption, non-cons – tungsten (gradually depleted)
Resistance Spot Welding: Current flow thru cross section of spot weld, generate heat w resistance
SSW: 1. Roll Bending: Roll melt tgt w pressure,
2. Friction Welding: Twist parts in contact to generate heat > Narrow Heat Affected Zone (HAZ), join dissimilar metal, 3. Explosive Welding: Clad metal over large areas
Weld quality:
HAZ: microstructural changes to metal tht experience temp. below melting > usually-ve

Weld Defects: Incomplete fusion: low quality weld beads, formation of oxide, incomplete fusion at grooves

Cracks cause: 1. Thermal stressed (temp. gradient) 2. Variation in composition 3. Embrittlement of grain boundaries (segregation)

4. Hydrogen embrittlement 5. inability to contract
Distortion: Differential not expansion/ cold contraction of diff. part of welded assembly

Others: 1. Brazing: filler metal of low melt.p > 450 , no melting base only filler. Metal of poor weldability + ceramics. Increased contact area is good 2. Soldering: brazing but melt.p <450. Filler metal called solder, usually for electrical. 3. Adhesive bonding: basically glue, need large contact area for good bond.

Chapter 11: Engineering polymers & Polymer forming
Polymer Molecule: Monomer unit (H-C-H) joined by covalent bonds.
Polymer Structure: Linear Polymer: chains of polymer lying on each other, inter-chain bonds weak. Branched Polymer: like a tree (chain packing efficiency↓)
Crosslinked polymer: adjacent linear chain joined by strong covalent bonds, achieved by growth at high temps and is irreversible i.e Rubber. Network polymer: trifunctional monomer units that form more than 3 covalent bonds -> 3-D network. i.e Epoxies
Types of polymers: Thermoplastics – soften upon heating, made to flow with stress. Solidify when cooled. Recyclable. Thermoset – becomes irreversibly hard/rigid when heated. Chain motion restricted by high degrees of cross-linking. Stronger but better dimensional stability compared with thermoplastic. Non-Recyclable. Elastomers – like rubber, linear/cross-linked. Chains extend on deformation but don't flow due to crosslinks. Returns to original shape.
Glass Transition: temp that polymer rubber<->glass,
T_g Factors: 1) easily deformed-> low T_g, 2)Larger molecular weight -> T_g↑ 3) Cross linking ↑T_g

Polymer melts: hot thermoplastic act like its liquid.
Viscosity: measure of internal friction. Polymer->high Viscosity (low fluidity). ↑Shear rate/↑T, viscosity↓
Viscoelasticity: Over time, strain will increase gradually under stress, and cannot return to 0 strain after unload. E.g., Die swell extruded polymer return to previous shape
Polymer forming: net shape process, lesser energy than metals, no plating required, unlimited geometry.
Casting: same as metal basically
Extrusion: Barrel: electric heater melts feed stock Screw: feed(pellets), compression (transform into fluid, air extracted, material compressed) metering (melt homogenized and pumped through die opening) Die: pass through screen pack (filter, build pressure, straighten flow of polymer melt)

Injection molding: Injection system – much like extrusion, screw used for mixing and ramming molten plastic into mold. Contains non-return valves to prevent backflow| Clamping system – holds 2 halves of mold, keeps mold closed during injection with force
Molds: 2 plate – 2 cavities to produce 2 times of expected mold. Oversized to allow for shrinkage. Contains ejection system with pins to eject molded part. Cooling system (water circulated) & air vents for evacuation of air. 3 plate – uses 3 plates to separate sprue and runner when mold open. **PROS:** runner and parts disconnect when mold opens, allows automatic operation. Hot-Runner – heaters around sprue and runner so no solidifcation of polymers (reduce waste)
Shrinkage: linear shrinkage - $D_c = D_p + D_pS + D_pS^2$
D_c =dimension of cavity, D_p =molded part, S= shrinkage
Factors: 1. injection pressure↑, shrinkage↓
2. Compaction time↑, shrinkage↓ 3. T↑, shrinkage↓
4. Thicker part, more shrinkage
Defects: 1. Short shot: solidified before cavity filled (fix:T,P↑)
2. Flash: polymer squeeze into parting surface/around ejection pins (causes: large vents/clearance, high injection P, T too high)
3. Sink marks – too thick of a molded section, insufficient mat.(fix:P↑, design similar thickness sections)
4. Weld line – never join fully when polymers meet(fix:T,P↑)
Compression molding: pelletes, compress, hold, open Simpler than injection mold, no spure & runner, simpler geometry, mold must be heated. Ex: Socket plug
Transfer molding: compression molding as fluid. Thermoset loaded into chamber, heated, then pressure applied on soft polymer to flow into heated mold, cured Pot: charge injected from a pot| plunger: injects charge from a heated well. (vs compression) 1. Both have unreusable scrap(cull) 2. Transfor molding more intricate coz fluid, good for molding with inserts
Blow molding: thermoplastic only, using air pressure to inflat soft plastic into mold cavity. 1. Form starting tube (parison)extrusion/injection 2. Inflation of tube Types: extrusion BM – parison extruded | injection BM – parison injected into mold before blowing | Stretch BM – injection, stretch (by blowing rod) THEN blow.
Thermoforming: sheet heated, placed over mold cavity,vaccumm draws sheet to form shape,cured. ONLY THERMOPLASTICs
Pressure TF – done in pressure box to use pressure from ABOVE to push plastic down. Mechanical TF – Positive mold pushes from above Good dimensional control, surface details on both sides but costly.


Chapter 6: Overview of Manufacturing

Metal Casting – casting Metal Forming – extrusion Metal Machining – drilling, milling Metal Joining – welding

Additive Manufacturing – increase weight(3d printing)

Subtractive Manufacturing – decrease weight(Milling)

Formative Manufacturing – no weight change(Casting)

NET shape process: Little of no waste and no machining is required

Good environmentally conscious manufacturing: Proper choice of materials, design products that minimize environmental impact. Manufacturing processes that are environmentally friendly

Dimensions: Part sizes desired by the designer if the part could be made with no errors or variations.

Tolerance: Total amount by which a specific dimension is permitted to vary

Tolerance = positive tolerance – (negative tolerance)

ACCURACY: True value of the quantity **PRECISION** : degree of repeatability

Apparatus: micrometre – diameter, vernier calliper, bevel protractor, sine bar (sin Angle = Height/Length)

Surface Roughness: Average vertical deviations from nominal surface over a specified surface length

$R_a = \sum_{i=1}^{n} \frac{|y_i|}{n} = \frac{y_1+y_2+y_3}{n}$ (ABS VALUE, no sign)

Chapter 7: Metal Casting

PROS: Create complex geometries for both external and internal shapes. Large parts, suited for mass productions. (Near) Net Shape.

CONS: Environmental problems. Safety hazards to workers, poor dimensional accuracy and surface finish, limitations on mech. properties.

Terminology - Cope (Upper half of mold), Drag (Bottom half), Flask (Box contains the mold halves), Parting Line, Core (Used for interior geometry), Downsprue (a runner towards the main cavity),Pouring cup, Riser (Compensate for shrinkage & freeze later), Gate

Flow velocity $V_2 = \sqrt{2gh_1}$ (cm/s)

Fluidity – how fast to fill the cavity

High Viscosity = Low Fluidity

(Spiral test)

Continuity law

$Q = A_1(Vel)_1 = A_2(Vel)_2$ (cm^3/s)

Mold Filling: $T_{MF} = Vol/Q$ (cm^3)

Min. time, ignore friction.

Chvorinov's rule (Solidification)

$T_{TS} = C_m (Vol/A)^n$ [Entire **SURFACE** Area] Type of metal/density, temp/heat capacity

Net Shape: Complex features w/o additional operations.

Pouring of Metal

Pouring Temp: Raise temp to M.P, latent heat of fusion, raise temp. to desired pouring temp.

Rate: Slow, metal freeze before filling cavity. Fast, turbulence(cavity + degrade casting quality), irregular flow. Tapered Sprue - Prevents aspiration of air

Riser Design: Time for riser to solidify > Time for rest of casting to solidify - > Maximize V/A

Casting quality: Fluidity (too hard), Pouring temp (too low), Velocity (too slow), Improper design, turbulence, shrinkage

Casting General Defects:

Misrun: Casting solidified before completely filling mold cavity.

Cold Shut: Two position of metal flow together but there is a lack of fusion due to premature freezing.

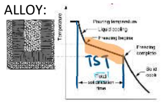
Cold Shot: Metal splatters during pouring lading to formation of globules, which become entrapped in the casting.

Shrinkage Cavity: Depression in the surface caused by solidification shrinkage that restricts molten metal to freeze. **Microporosity**: Small voids distributed throughout the casting caused by localized solidification shrinkage of final molten metal within dendritic structure.

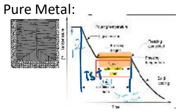
Hot Tears/Cracks: Casting restrained frm contraction because of mold from final stages of solidification or early stage of cooling.

Bernoulli's Theorem: $h_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = h_2 + \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + f$

ALLOY:



Pure Metal:



Achieving Directional Solidification: CHILLS (internal or external heat sinks that cause rapid freezing in certain regions of the casting

Product Design Considerations: Geometric Simplicity / Corners on the casting / Section thickness / Draft angle (taper) /eliminate the need of core / Dimensional tolerance & surface finish / Machining allowances.

Expendable mold casting: Investment Casting, Sand casting.

Sand Casting: Most widely used, nearly all alloys can be used, varying sizes can be done, high quantities produced

Investment Casting: 1.Wax pattern is produced. 2.Patterns attached to sprue to form pattern tree. 3. Tree is coated with layer of refractory material 4. Full mold is formed by covering coated tree with sufficient refractory material to make it rigid. 5. Mold held inverted position and heated to melt wax and permit it to leak out of the cavity. 6. Mold preheated to high temp, molten poured & solidify. 7. Mold is broken away from the finished casting and parts are separated from the sprue.

PROS: Net shape process, wax can be reused. Close dimensional control, good surface finish.

CONS: Expensive and many steps required.

Permanent Mold Casting (aluminium magnesium iron) Mold is preheated & coated for lubrication & heat dissipation. Cores (if used) are inserted, and mold is closed. Molten metal poured into mold & solidifies.

PROS: Dimensional control and surface finish. Rapid solidification results in finer grain structure so casting is stronger. Mold can be reused. Economical for large production. Thin sections possible.

CONS: Generally limited to metals of lower melting point, simpler part geometries compared to sand casting because need to open mold. Mold expensive.

Die Casting-high pressure to force metal into die cavity

Hot chamber die casting: Casting metals: zinc, tin, lead, and magnesium | Low MP | Heated Chamber

Steps: With the die closed and plunger withdrawn, molten metal flows into chamber. Plunger force metal flow to die under constant pressure. Withdraw ram; open die, eject parts

Cold Chamber die casting: Casting metals: aluminium, brass, and magnesium alloys | Unheated Chamber

Steps: With the die closed and ram withdrawn, molten metal is ladled (thus extra time) into chamber. Ram forces metal to flow into die, maintaining pressure during cooling and solidification. Withdraw ram; open die, eject part

PROS: Economic for large production, good accuracy, thin section possible, rapid cooling - small gain size & good strength of the cast product.

CONS: Limited to metal with low melting point, part geometry limited for removal from the die.

Chapter 8: Metal Forming

Sheet metal working: Thickness of sheet metal = 0.4mm to 6mm, larger=plate

Rolling: Hot rolling – above T_{recrys} Cold rolling- below.(better surface finish as no scale formation, better tolerance and better mech properties.

2/3-high rolls: used for hot rolling(3 reverse direction)

4-high: smaller diameter rolls, lower rolling force, reduce spreading. Usually cold rolling. (planetary)

Rotary tube piercing – hot-working process for long thick-walled seamless pipes. Round bar subjected to radial compressive forces and develops tensile stresses at its centre-> cavity. Internal mandrel expands hole and defines bore of tube

Done by: Ho Min Han

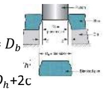
Sheet metal forming:

PROS sheet metal: Strong, dimensionally accurate, good surface finish, low cost, mass production

Blanking & punching: shearing operation

Rollover: Depression made by punch. Burnish: Smooth region due to penetration. Fracture zone: Quite rough surface due to fracture. Burr: Sharp corner edge due to elongation of metal. Shearing: Separate large sheets Blanking: Cut part perimeters from sheet metal. Punching: Make holes. Clearance: usually 2-10% T

Clearance: As c↑, sheet pulled into clearance zone rather than sheared, gives rougher edges, burr height↑, punch force↓, die wear↓ c = at, a = allowance, t = thickness



Round blank D_b:

Punch diameter: D_b-2c, die diameter = D_b

Round hole D_h:

Punch diameter = D_h, die diameter = D_h+2c

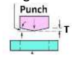
Angular clearance – allow blank to drop (0.25 – 1.5)◦

Max Punching Force: F = 0.7(UTS)TL = STL , S = Shear Strength, T = sheet thickness, L = length of shear(perimeter), UTS = ultimate tensile strength

Changing die reduces cutting force:

Bevel shear i.e where the centre

cuts first followed by outside

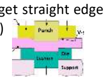


Other Shearing operations:

Shaving – extra material removed to get straight edge (small clearance between punch & die)

Fine Blanking – Blanking with a cushion below + pressure pads

c<=1%T



Bending

Bend Allowance, L_b

$L_b = \alpha(R + kT)$,

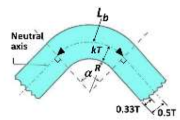
α = bend angle (rad)

R = bend Radius

k = constant(0.33~0.5)

T = sheet metal thickness

R<2T, k = 0.33 R>=2T, k =0.5



Minimum bend radius: eng strain e is $e = \frac{1}{\left(\frac{2R}{T}\right)+1}$

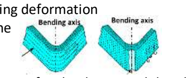
As R/T ↓, tensile strain at outer fibre ↑, causing cracks. Cracks first occur -> min bend radius. Usually expressed in terms of T.

Anistropy: different behaviour in diff directions, acquired during sheet metal processing (rolling)

1. preferred grain direction – caused by compression of equiaxed grains, boundaries align horizontally (preference in grain orientation)

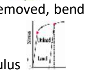
2. Mechanical fibering – alignment of impurities, inclusions, and voids during deformation

=>bending should be done perpendicular to rolling direction



Springback: elastic recovery after load removed, bend angle ↓, bend radius↑

$\frac{R_i}{R_f} = 4\left(\frac{R_i Y}{ET}\right)^3 - 3\left(\frac{R_i Y}{ET}\right) + 1$ Y = yield stress, E = Elastic modulus

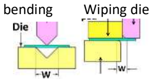


Compensation: Overbending, bottoming (high compressive pressure causes plastic deformation to reduce thickness at bend area) & stretch bending (sheet stretched past yield stress then bent). Including Ribs or darts can increase stiffness and ↓springback

Bending operations: V- die bending Wiping die

V- die- simple, cheap, acute obtuse

Wiping die- complicated, high quantity, precise



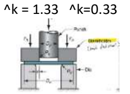
Bending force: $P = \frac{k(UTS)LT^2}{W}$ ^k = 1.33 ^k=0.33

L = bend length

Deep Drawing: Clearance = 1.1 t

1. Blankholder holds sheet metal

In place. 2. Punch moves down, bends sheet metal 3. Straighten to form cup wall, high tension along walls and high compression in flange, causes tearing and wrinkling respectively



B_holder force: too high -> tearing, too low-> wrinkles

Drawability: DR,reduction, thickness-diameter ratio

Drawing Ratio (DR) = blank diameter/punch diameter

If DR>2.0, not feasible

Reduction: (Db-Dp)/Db [%reduction in diameter] r<0.5

Thickness to diameter ratio: t/Db > 0.01

t/Db↓, tendency to wrinkle ↑

If conditions are not met, redrawing is required, with annealing between each drawing.

Redrawing: Drawn cup faced UPWARDS on die

Reverse Drawing: Drawn cup faced DOWNWARDS on die – requires lesser force than redrawing

Blank size: Volume doesn't change!

Drawing Force: $F = \pi D_p t(TS)\left(\frac{D_b}{D_p} - 0.7\right)$

0.7 accnts for friction

Blankholder Force:

$$F_h = 0.015Y\pi\left\{D_b^2 - \left(D_p + 2.2t + 2R_d\right)^2\right\}$$

Drawing defects: wrinkling, tearing, earing(anistropy), surface scratches

Chapter 9: Metal Machining

PROS: Good dimensional accuracy and surface finish

CONS: Waste materials, takes a long time to shape

Cutting Models: Oblique(<90deg) & Orthogonal(90◦)

V = Cutting velocity

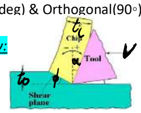
α = rake angle

ø = shear angle

t0 = undeofrmed thickness

tc = chip thickness

side view:



Merchant's equation: assumed that ø adjusts itself to give minimum cutting force (use when given) β = friction angle

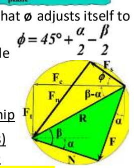
$\phi = 45° + \frac{\alpha}{2} - \frac{\beta}{2}$

Cutting Forces: $R = \sqrt{F_c^2 + F_t^2}$

Friction coeff: $\mu = F/N = \tan\beta$

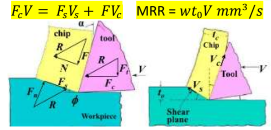
Shear stress = $\frac{F_s}{A_s}$ (w = width of chip

$A_s = wt_0/\sin\phi$ NOT thickness)



Power & Material Removal Rate

$F_c V = F_s V_s + F V_c$ MRR = $wt_0 V$ mm^3/s



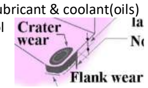
Specific energy = Power/MRR J/mm^3

Energy conservation applies here!

Temperature: energy lost converted to heat => shear zone & tool chip interface

T↑ -> 1. Strength,hardness,wear resistance↓ (cuttingtool) 2. Dimensional inaccuracies in w/p, thermal damage, fail easier(Workpiece) 3. Uneven temps distort machine, difficult to control dimensions (machine tools) **Cutting fluid:** Lubricant & coolant(oils)

Tool wear: flank (rubbing of tool & high temps) & crater (high Temp & checmical affinity with w/p -> use coated with TiN)



Signs for replacement: 1. Obvious tool wear 2. w/p surface finish gets worse 3. F_c ↑signif 4.T↑ signif.

Taylor's tool life eqn: $VT^n = C$ V= cutting speed, T = tool life(min), n= exponent(<1) ,C=constant

$VT^n d^x f^y = C$, d= depth of cut mm, f = feed mm/rev

Cutting tool material: 1) Hot hardness 2) Toughness 3) Thermal shock+Wear resistant 4) Chemically stable

Types of chips: continous – ductile material, good surface finish, entangles tools [Change machining parameters or use chip breaker]|Discontinous – brittle materials, hard impurities, cutting force varies during cutting |Built-up edge – layers of w/p deposited on tool. BUE↑, tool breaks. Some BUE will be deposited on w/p surface, poor surface finish. BUE also makes tool dull | Serrated – low thermal conductivity & strength decreases with temperature

Surface finish: factors: Chip types, feed mark left by cutting, vibration*

$R_a = \frac{f^2}{32R}, R_t = \frac{f^2}{8R}$ (peak to valley)| either↑,finish ↓

*forced – force from machine tool, chattering – self-excited vibration from interaction of cutting process and machine tool. Starts from disturbance in cutting

Others: 1.Turing:MRR = depth of cut * feed * rota. V

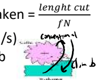
V = $\pi D_{avg} N$, N = rotation speed, D_{avg} = (Di+Df) /2

Cuts at high f, then lower f for good surface finish

Drilling: MRR=$\frac{\pi D^2}{4} fN$, f = feed. Time taken = $\frac{lenght\ cut}{fN}$

Power = torque * rotational speed (rad/s)

Milling: Conventional (upwards) + climb milling(downwards)



Conventional -max thickness at end of cut, does not affect tool life, will chatter so need clamp w/p climb – max thickness at start of cut(bad), downward cutting force holds w/p in place(good), scales will cause dmg on cutter, high impact forces require rigid set up.

Grinding – dimensional accuracy and surface finish

Chapter 10: Metal Joining

Welding: Fusion Welding: melts base metal, sometimes have filler metal(w/o – autogenous)

Solid State Welding: no melting of base metal, no filler metal is added

Power:Power density=P/A | intensity of power within A

Unit energy for melting = kT_m^2, k = 3.33*10^-6, T in kelvin

Heat transfer: f_1- (heat received by w/p) / total heat)

f_2- proportion of heat received by w/p used to melting

=> $H_w = f_1 f_2 H$, H_w= heat for welding, H = total heat

f_1 – affected by welding process

f_2 – affected by thermal conductivity& welding process

Energy Balance: Welding speed $v = \frac{f_1 f_2 H_{Rate}}{U_m A_w}$

A_w= weld area, H_{rate} = rate heat is generated from source. Welding volume rate =HR_w/U_m , HR_w = rate of energy delivered.

Arc Welding: using electric arc to heat metal

Shielding: inert gas or flux(flux prevents formation of oxides & provides protective atm. Stabilises arc, reduce spattering) Application of flux: coat electrode with flux which melts during welding. Or flux contained in core of consumable electrode, flux release as it is consumed.

Electrodes: Consumable – filler metal, non-consumable – tungsten(gradually depleted)

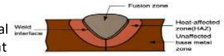
Resistance Spot welding: current flow thru cross section of spot weld, generate heat with resistance.

SSW: Roll Bonding – roll metal together with pressure

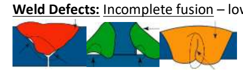
Friction welding: twist parts in contact to generate heat - narrow HAZ, join dissimilar metals| Explosive Welding – clad metals over large areas

Weld quality:

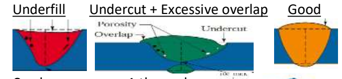
HAZ – microstructural changes to metals tat experience temp below melting – usually negatively



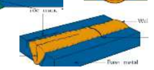
Weld Defects: Incomplete fusion – low quality weld beads, formation of oxide, incomplete fusion at grooves



Underfill Undercut + Excessive overlap Good

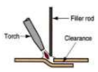


Cracks – cause: 1.thermal stressed(temp gradient) 2.Variation in composition 3. embrittlement of grain boundaries(segregation) 4.hydrogen embrittlement 5. inability to contract



Distortion: differential thermal expansion and contraction of different parts of welded assembly

Others: Brazing: filler metal of low MP(>450C), no melting of base metal only filler. For metals of poor weldability + ceramics. Increased contact areas is good



Soldering: brazing but MP<450. Filler metal called solder, usually for electrical. Adhesive bonding: basically glue, need large contact areas for good bond.

Chapter 11: Engineering polymers & Polymer forming

Polymer Molecule: Monomer unit (H-C-H) joined by covalent bonds.

Polymer Structure: Linear Polymer: chains of polymer lying on each other, inter-chain bonds weak. Branched Polymer: like a tree (chain packing efficiency↓) Cross-linked polymer: adjacent linear chain joined by strong covalent bonds, achieved by growth at high temps and is irreversible i.e Rubber Network polymer: tri-functional monomer units that form more than 3 covalent bonds -> 3-D network. i.e Epoxies

Types of polymers: Thermoplastics – soften upon heating, made to flow with stress. Solidify when cooled. Recycable. Thermoset – becomes irreversibly hard/rigid when heated. Chain motion restricted by high degrees of cross-linking. Stronger but better dimensional stability compared with thermoplastic. Non-Recyable. Elastomers – like rubber, linear/cross-linked. Chains extend on deformation but don't flow due to cross-links. Returns to original shape

Glass Transition: temp that polymer rubber<->glass,T_g

Factors: 1) easily deformed-> low T_g 2)Larger molecular weight -> T_g↑ 3) Cross linking ↑T_g

Polymer melts: hot thermoplastic act like its liquid. Viscosity: measure of internal friction. Polymer->high viscocity(low fluidity). ↑Shear rate/↑T, viscosity↓

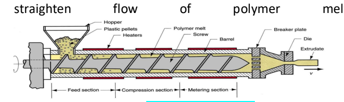
Viscoelasticity: Over time, strain will increase gradually under stress, and cannot return to 0 strain after unload Ex: Die swell extruded polymer return to previous shape

Polymer forming: net shape process, lesser energy than metals, no plating required, unlimited geometry.

Casting: same as metal basically

Extrusion: Barrel: electric heater melt feed stock Screw:feed(pellets),compression(transform into fluid, air extracted, material compressed) metering(melt homogenized and pumped through die opening)

Die: pass through screen pack (filter,build pressure, straighten flow of polymer melt)



Injection molding: Injection system – much like extrusion, screw used for mixing and ramming molten plastic into mold. Contains non-return valves to prevent backflow| Clamping system – holds 2 halves of mold, keeps mold closed during injection with force

Molds: 2 plate – 2 cavities to produce 2 times of expected mold. Oversized to allow for shrinkage. Contains ejection system with pins to eject molded part. Cooling system(water circulated) & air vents for evaculation of air. 3 plate – uses 3 plates to separate sprue and runner when mold opens. PROS: runner and parts disconnect when mold opens, allows automatic operation. Hot-Runner – heaters around sprue and runner so no solidifcation of polymers (reduce waste)

Shrinkage: linear shrinkage - $D_c = D_p + D_p S + D_p S^2$

D_c=dimension of cavity, D_p=molded part, S= shrinkage

Factors: 1. injection pressure↑,shrinkage↓ 2. Compaction time↑, shrinkage↓ 3. T↑, shrinkage↓ 4. Thicker part, more shrinkage

Defects: Short shot – solidified before cavity filled (fix:T,P↑) | Flash: polymer squeeze into parting surface/around ejection pins (causes: large vents/clearance, high injection P, T too high) | Sink marks – too thick of a molded section, insufficient mat.(fix:P↑, design similar thickness sections) | Weld line – never join fully when polymers meet(fix:T,P↑)

Compression molding: pelletes, compress, hold, open Simpler than injection mold, no spure & runner, simpler geometry, mold must be heated. Ex: Socket plug

Transfer molding: compression molding as fluid. Thermoset loaded into chamber, heated, then pressure applied on soft polymer to flow into heated mold, cured Pot: charge injected from a pot| plunger: injects charge from a heated well. (vs compression) 1. Both have unreusable scrap(cull) 2. Transfor molding more intricate coz fluid, good for molding with inserts

Blow molding: thermoplastic only, using air pressure to inflat soft plastic into mold cavity. 1.Form starting tube (parison)extrusion/injection2.Inflation of tube

Types: extrusion BM – parison extruded | injection BM – parison injected into mold before blowing | Stretch BM – injection, stretch (by blowing rod) THEN blow.

Thermoforming: sheet heated, placed over mold cavity,vaccumm draws sheet to form shape,cured. ONLY THERMOPLASTICs

Pressure TF – done in pressure box to use pressure from ABOVE to push plastic down. Mechanical TF – Positive mold pushes from above Good dimensional control, surface details on both sides but costly.