Engineering in Chemical and Pharmaceutical Processes

Tablet compression

Tablet press tooling

Steps in tablet compression

Tablet press

- Rotary
  - several dies

- Single-punch
  - one die
**Powder compaction during compressing the tablets**

**Material properties**
- Compressibility = ability to reduce volume
- Compactibility = ability to form strong compacts

**Energy analysis of compaction**
- Analysis of force required per displacement during compression and decompression
- Energy = force * length
- Energy = area under curve
  - $E_p$ = plastic deformation
  - $E_e$ = elastic deformation
  - $E_f$ = rearrangement / friction

**Compression phases**
- Particle rearrangement
- Deformation on contact points
- Fragmentation
- Bonding
- Deformation of solid body
- Decompression
- Ejection

**Particle rearrangements**
- Low pressure - big volume reduction
- Particles changing orientation, move, fill void spaces, percolate
- Better flowability means less rearrangement

**Deformation**
- Deformation occurs under pressure
  - elastic
  - plastic
- Plastic deformation occurs at yield pressure
- Deformation develops increased contact area - therefore new bonds
Fragmentation

- Exceeding the material strength causes fragmentation of original particles
- Fragmentations enable further compression and develop new surface for bonding
- Fragmentation is typical for less plastic materials

Force balance in die

- Pressure developed by upper punch $F_U$; lower punch force $F_L$ is different
- Axial profile of strength $F_L = F_U e^{-k\frac{H}{D}}$
  - $k$ ... material constant
- Force balance $F_L + F_U = F_U$
  - $F_U$ ... friction force
- Mean force provides better information than $F_U$

Compression equations

- Heckel equation
  \[
  \ln \left( \frac{1}{1 - \rho_p} \right) = kp + A \left( \rho_p - \rho_0 \right)
  \]
  - $\rho_p$ = projected rel. density at zero pressure
- $k$ ... yield pressure
- $A$ ... initial plast. def.

Heckel plot

- Heckel equation fits only the linear section II

Compression equations

- Kawakita equations
  \[
  C = \frac{V_0 - V}{V_0} = \frac{ab}{1 + ab}
  \]
  - $a$ = maximum compression
  - $b = \rho_0$ pressure required to reduce volume by 50 %
  - low value = more plastic deformation
Heckel-Kawakita analysis

- Heckel equation - linear relationship at high pressure
- Kawakita equation - linear relationship at lower pressure
- different meaning of $p_y$ and $p_k$
  - $p_y$: onset of plastic deformation (time dependent)
  - $p_k$: measure of plastic deformation (time dependent)
- $p_y$ and $p_k$ differ at longer residence time
- common interpretation of Heckel and Kawakita parameters

Bonding

- Different mechanisms
  - Mechanic - mechanic interlocking of particles
  - Intermolecular theory - interactions between molecules at surface of particles (e.g., van der Waals)
  - Liquid film theory - high pressure at contact edges aids dissolution/metling
  - most insoluble materials have poor compactibility
  - dry powders are poorly compactable

Solid body deformation

- Further compression = densification, less porosity
- Different radial and axial stress
  - lateral stress ratio (Poisson ratio)

Decompression

- On decompression - elastic springback - develops stress in the tablet
- Tablet must withstand this stress
- Stress released by
  - plastic deformation of tablet
  - fragmentation of the tablet
- Effect of tablet press speed - decompression rate
  - rate determines residence time - rate of crystalization (liquid film theory) - crystal strength

Tablet ejection

- Tablet expands only axially while contained in the die
- Radial expansion after leaving die (2 - 10 %)
- Tablet may disintegrate
  - lamination
  - capping