

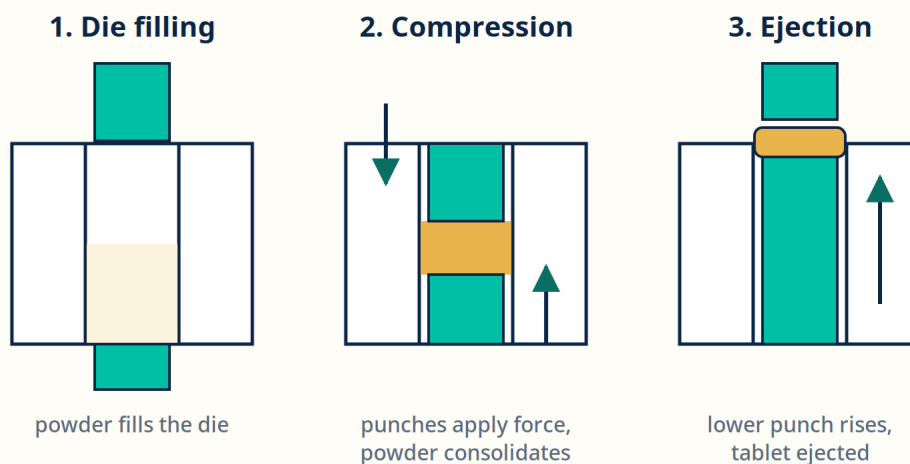
4.1 Physics of tablet compression

Tableting converts a powder or granulation into a compact of definite shape, strength and weight by applying pressure between two punches inside a die. The physics of this event decides the quality of every tablet: its hardness, friability, disintegration and dissolution. The process on a rotary press runs in stages:

- 1 **Die filling:** the lower punch drops and the die fills with a measured volume of feed from the hopper, usually with the help of a feed frame. Fill uniformity decides weight uniformity.
- 2 **Metering and pre-compression:** the lower punch rises to the exact fill position, excess feed is removed, and on many presses a small pre-compression force removes entrapped air.
- 3 **Main compression:** the upper punch enters the die and the punches move towards each other, applying the main force; the powder consolidates into a tablet.
- 4 **Decompression and ejection:** the upper punch withdraws, the pressure releases (the compact relaxes slightly, called elastic recovery), and the lower punch rises to push the tablet out of the die, where it is swept away.

A tablet press records force against time or punch travel; these traces are the raw material of sections 4.5 and 5.5.

Stages of Tablet Compression



Upper punch shown in teal above, lower punch below the die cavity

Figure: The stages of one compression cycle on a tablet press: die filling, compression, then decompression and ejection.

4.2 Compression and consolidation: what happens inside the die

As pressure rises, the powder bed consolidates in a recognisable sequence of mechanisms:

- **Particle rearrangement:** at low pressure, particles slide and rotate into the voids, and packing density rises with little true deformation. Fine particles fill gaps between coarse ones.

- **Elastic deformation:** particles deform reversibly; the deformation disappears when pressure is removed and contributes to elastic recovery.
- **Plastic deformation:** beyond the yield point, particles flow permanently into new shapes, greatly increasing the area of contact between them. Materials such as microcrystalline cellulose consolidate mainly this way.
- **Fragmentation (brittle fracture):** hard, brittle materials such as lactose and dicalcium phosphate break into smaller pieces, creating fresh, clean surfaces that bond well; fragmentation is largely independent of compression speed.
- **Bonding:** the enlarged, closely pressed surfaces bond by intermolecular forces (van der Waals), by solid bridges formed where local heat or pressure causes fusion, and by mechanical interlocking. The total bonded area, created by deformation and fragmentation, is what gives the tablet its strength.

Consolidation is the sum of these mechanisms. Whether a material prefers plastic flow or fragmentation explains its behaviour: plastic materials are sensitive to lubrication and to press speed (less time to flow gives weaker tablets), while brittle materials are more forgiving of both. Most formulations mix the two types deliberately.

4.3 Effect of friction

Friction acts at two places. Interparticle friction between particles resists their movement during rearrangement; die wall friction, between the compact and the die wall, is the bigger practical problem. As the upper punch pushes down, the die wall friction opposes the movement, so the force reaching the lower part of the compact is less than the applied force. Consequences:

- **Uneven density:** the top of the tablet is denser than the bottom, worst in tall, thin compacts; this can cause capping and lamination on ejection.
- **High ejection force:** the tablet must be pushed out against the friction of the die wall; a large residual radial force makes ejection hard and can score or break tablets.
- **Heat and wear:** friction converts work into heat, warming punches and dies and accelerating tooling wear.

Lubricants such as magnesium stearate reduce die wall friction by forming a film on the die wall and on particle surfaces. The price of lubrication is bonding interference: the same film coats particle surfaces and weakens tablet strength, especially in plastic materials, and excessive lubricant or over mixing slows wetting and dissolution. Antiadherents and glidants handle related problems: sticking to punch faces and poor powder flow respectively. Managing friction is therefore a balance: enough lubricant to eject cleanly, never so much that the tablet weakens.

4.4 Distribution of forces

Force applied by the upper punch is not transmitted perfectly through the compact. The ratio of the force measured at the lower punch to the force applied at the upper punch is called the force transmission ratio (or R value). In a perfectly lubricated, frictionless system it would be 1; in practice it is reduced by die wall friction, and it is a sensitive measure of lubrication quality: values above about 0.9 indicate a well lubricated system.

Within the compact, stress exists in two directions: axial stress along the punch movement, and radial stress pressing the compact against the die wall. During compression the radial pressure rises with the axial pressure; at the end of decompression a residual radial pressure remains, which is what makes ejection force necessary. The radial pressure also explains elastic recovery behaviour and the splitting

tendency of tablets: while axial pressure is released fully when the upper punch leaves, the compact is still squeezed radially inside the die, and sudden release of this stress at ejection can split weak compacts. Measurement of upper and lower punch forces, ejection force and residual radial pressure, using instrumented presses and instrumented dies, is the experimental base for all compaction science in this unit and the next.

4.5 Compaction profiles

A compaction profile is a recorded relationship during the compression cycle that converts the event into data. The common profiles are:

- **Force time profile:** force plotted against time through one cycle; shows the rise, dwell and fall of pressure and detects sticking or irregular feeding.
- **Force displacement profile:** force plotted against punch travel or punch separation. The area under the curve is the work of compression, and its shape separates the work used in consolidation from the work returned as elastic recovery during decompression. Comparing profiles of formulations shows which one consolidates easily and which wastes energy on friction or elasticity.
- **Pressure porosity (density) profile:** the relative density of the compact plotted against applied pressure (often in logarithmic form), summarising how a material densifies; it is the parent plot of the Heckel analysis of Unit 5.
- **In-die thickness and recovery measurements:** the thickness of the compact under load and after ejection, giving elastic recovery directly.

Profiles are used to compare materials and formulations, to select lubricant levels, to detect over pressing (where extra force adds no strength, only capping risk) and to transfer a process between presses by matching profiles rather than only machine settings.

4.6 Solubility

Solubility is the maximum amount of a solute that dissolves in a given amount of solvent at a given temperature, forming a saturated solution. In pharmaceuticals it is usually expressed for the drug in water or in buffer at body temperature, in mg per mL or as descriptive terms from practically insoluble to freely soluble. Solubility matters in this subject at two points: a drug must dissolve before it can be absorbed, so aqueous solubility and dissolution rate together limit bioavailability for most oral products; and within the tablet, the solubility of the drug and of excipients influences consolidation behaviour and what happens when the compact meets liquid: a soluble filler such as lactose dissolves at the surface and aids disintegration and release, while an insoluble matrix holds its structure.

Factors affecting solubility include the nature of the drug crystal (polymorphs differ in solubility, with metastable forms more soluble and less stable), particle size (smaller particles dissolve faster and very fine particles are slightly more soluble), temperature, pH for ionisable drugs (a weak base dissolves better at low pH; salts of weak acids and bases are chosen to exploit this), and the presence of solubilising agents. The pH solubility profile and the salt form of a drug are therefore decided in preformulation (Unit 1), and revisited here because they decide whether a compressed tablet can deliver its drug into solution at all.