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The effect of punch tip geometry on powder movement during the tableting process

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Axial and radial powder movements during the tableting process have been studied using punches with various tip geometries. Radial powder movement has been shown to occur. Alteration of punch tip geometry did affect both axial and radial powder movement, the extent being dependent on the relative curvature of the punch tip. Addition of lubricant decreased relative axial movement but had little effect on radial movement.

During the tableting process there is differential movement of powder within the die, the central portion showing relatively greater movement than that at the periphery. This has been explained in terms of the frictional forces at the die wall/particle interface being greater than interparticulate frictional forces (Bal'shin 1938; Kamm et al 1947). This phenomenon has been studied by X-ray measurement of deformable lead grids within the compact (Kamm et al 1947), alternate differently coloured layers of powder (Train 1956), deformation of resistance gauges within the powder mass (Train 1957), and, more recently, autoradiography using compacts prepared from radioactive material (McCleod 1976).

The earlier studies, using flat faced punches showed lubrication to decrease the amount of relative movement between particles at the periphery and the centre of the powder mass and several claimed to show no radial movement of powder during compression (Bal'shin 1938; Unckel 1945; Kamm et al 1947; Train 1956).

There have been very few attempts to study tableting using punches with curved surfaces or bevelled edges as are commonly used in the Pharmaceutical Industry. One investigation (Aulton & Tebby 1975) did in fact show that alteration of punch face geometry changed the distribution of surface hardness, suggesting changes in the packing of the particles near to the surface. It is not therefore improbable that changes take place not only adjacent to the surface but also throughout the tablet and this investigation was carried out to test the validity of this hypothesis.

MATERIALS AND METHODS

The compacts were prepared from Avicel PH101 (F.M.C. Corpn., Marcus Hook, U.S.A.). This powder has been granulated before compression, one batch being granulated with water and the other using a 1% w/v methylene blue solution. The granulating conditions for both batches were otherwise identical, namely 500 g Avicel pH 101 and 200 ml granulating fluid, mixed for 10 min in a Z blade mixer (Baker Perkins, Peterborough), passed through a 210 μm mesh on an oscillating granulator (Manesty Machines Ltd., Liverpool), dried to a final moisture content of 5% w/w and repassed through a 210 μm mesh. The moisture content of the granules was determined using an Ohaus moisture balance. The prepared granules were mechanically sieved and the 105–180 μm fractions were retained and stored in sealed jars until compressed.

Compacts were prepared in a split die, based on that used by Train (1956) but the internal diameter of the present die was only 30 mm.

Two types of compacts were prepared. Both were prepared from alternate coloured and uncoloured layers of material, horizontal layers being used to study axial powder movement and vertical layers to study radial powder movement.

Each type of compact was compressed at five levels of compressional force 4.9, 9.8, 24.5, 49.0, 98.1kN, using a hydraulic press in both the unlubricated state and after the addition of 0.5% w/w magnesium stearate (Hopkins, Williams Ltd, Chadwell Heath) as a lubricant.

Conditions were controlled so that each layer was initially of equal bulk density. After compression the tablets were ejected in the opposite direction to that which had been used for compression. Each compact was then cut horizontally using a band saw.

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This exercise was repeated for all four shapes of punch tip.

RESULTS AND DISCUSSION

The results obtained for the axial powder movement studies are shown in Fig. 1 for all punch tip geometries and pressures used. More detailed features are shown in Fig. 2 using compacts prepared at 98.1kN compressive force.

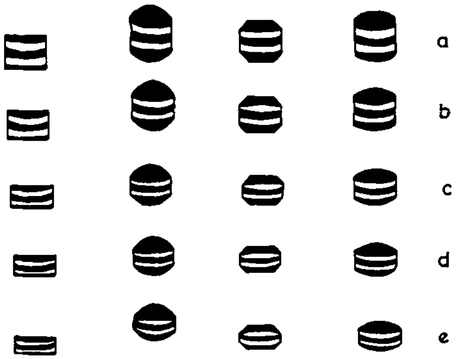

FIG. 1: Axial powder movement studies a 4.9kN; b 9.8kN; c 24.5kN; d 49.0kN; e 98.1kN.

All the compacts, irrespective of curvature and compaction pressure used, showed relative particle movement between the centre and the periphery, agreeing with earlier findings (Kamm et al 1947; Train 1956).

Considering the flat faced punch, the situation is similar to that envisaged by Train (1956). The compressional force acting on the particles within the powder bed is accommodated by increase in local stresses, resolution of which shows the resultant force to act towards the bottom half of the compact, creating an area of higher relative density. Between this region and the moving punch face a protected region develops subjected only to compressive forces and undergoing relatively little compression. This can be seen in Fig. 2 where in the central region of the tablet the thickness of banding is uniform and is greater at higher levels in the tablet.

The relatively greater compression of the bottom half of the tablet is caused not only by stress relief within the part of the tablet adjacent to the moving top punch but also by reaction between the bottom punch face and the particles adjacent to it. The effect is more pronounced than that shown by earlier workers (Train 1956) as the present h/d ratio range of approximately 0.85–0.40 is lower than that previously used, 1·65–1·0, causing greater interaction of the two above mentioned forces in the lower half of the compact.

FIG. 2. Compacts showing axial powder movement prepared using an axial compressive force of 98.1kN.

As punch face geometry changes, so does the character of the central region. Die wall friction still impedes particle movement at the periphery of the compact. However, because of punch shape, there is greater axial movement in this region relative to the centre of the compact than is found with the flat faced punch. The central region adjacent to the punch face undergoes little axial movement, as demonstrated in Fig. 2 by the maintenance of the thickness of the central portion of the bands.

Resolution of compressional forces acting on the particles when the curved or bevelled edge punches are used, in a manner similar to that used for the flat faced punch, shows the resultant force to act downwards towards the centre of the compact. The angle of this resultant force is dependent on the curvature of the punch face; the greater the curvature, the nearer to the moving punch face is the action of the resultant force. In all cases however this force acts higher up the compact for the shaped punches than for the flat faced punch. In consequence the high pressure regions, which give rise to relatively denser areas, would be situated nearer the moving punch face. These areas, which partially support the compressional load, form protected regions, and are shown in Fig. 2 by the relative thickening of the central region of the banding in the upper part of the tablet. This effect is more pronounced in the order bevelled >deep concave >normal concave as would be expected from a consideration of the angles of the punch faces to the direction of compression.

As the resultant force is acting inwards towards the centre of the compact it would be expected that some lateral movement of particles would take place both during the particle re-arrangement stage of the consolidation process and by lateral compression of particles by the high density regions within the main body of the compact, these regions acting as secondary punch faces. The results of the lateral particle movement studies are shown in Figs 3 and 4.

Before compression the bands are all parallel and of equal bulk density. Any alteration in their geometry would indicate changes in the distribution of bulk density resulting from lateral particle movement. These geometrical changes were therefore used to

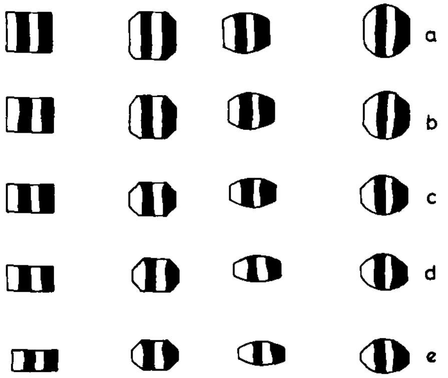

FIG. 3. Radial powder movement studies. Compressive forces as given in Fig. 1.

deduce the extent of lateral powder movement. There is a slight change in this geometry in the compact prepared using the flat faced punch, which becomes more pronounced as the geometry of the punch face alters. This suggests that as curvature of the punch face increases there is a corresponding increase in the tendency for lateral particle movement within the main powder body, which would be expected as the resultant force becomes more lateral in direction as curvature increases. This lateral movement will increase the tendency to form a high density region within the main body of the compact greatly increasing the protective effect afforded to the area between it and the punch face. Because this protected area is subjected only to compressive stresses, and not the shear stresses operating in the region subjected to compressive and lateral forces, it is relatively soft (Train & Hersey 1960) and stress boundaries will be set up at the interface between soft and dense regions. Capping will tend to occur along these stress boundaries and as the stress difference increases with increasing punch curvature the tendency towards capping would similarly become more pronounced.

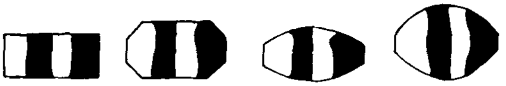

FIG. 4. Compacts showing radial powder movement prepared using an axial compressive force of 98.1kN.

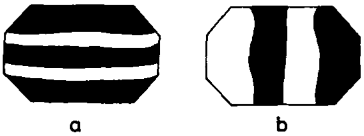

FIG. 5. Compacts showing (a) axial powder movement and (b) radial powder movement using bevelled edge punches and an axial compressive force of 98.1kN after addition of 0.5% w/w magnesium stearate.

Alteration in the stress distribution within the compact would also explain the changes in surface hardness observed by Aulton & Tebby (1975) as these changes would be not only a function of the material properties but also influenced by the structure of the compact immediately below the surface.

Addition of 0.5% w/w magnesium stearate as lubricant, shown in Fig. 5a, b, has the effect of decreasing both interparticulate and die wall friction demonstrated by the flattening of the horizontal banding in Fig. 5a. However, lateral movement of powder still occurs, Fig. 5b, demonstrating the dependence of lateral movement not solely on frictional forces acting within the compact but also on punch face geometry.

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