International Journal of Pharmaceutics, 48 (1988) 173–177
Elsevier

IJP 01628

Relationship between porosity and water content of dicalcium phosphate tablets

N. Anthony Armstrong, Anil N. Patel * and Trevor M. Jones **

Welsh School of Pharmacy, University of Wales Institute of Science and Technology, Cardiff (U.K.)

(Received 3 April 1988)
(Accepted 19 May 1988)

Key words: Dicalcium phosphate dihydrate; Tablet; Porosity; Water content; Yield force

Summary

The effect of water content on the consolidation of dicalcium phosphate dihydrate (Emcompress) tablets was examined. Increasing the moisture content of Emcompress resulted in an increase in apparent tablet density, both under compression and after ejection. This continued up to a critical water content, beyond which a reduction in densification was obtained. The magnitude of this critical water content was dependent on the applied compression force, in that it was decreased by an increase in compression force. Increasing the moisture content also caused a reduction in elastic decompression work and yield force values to a minimum, beyond which an increase in the values of both parameters was recorded.

Introduction

The reduction of porosity in a powder bed, i.e. consolidation, is an essential stage of tablet formation, since only after particles are brought into close proximity to each other can interparticulate forces exert a significant attractive effect. It is well known that the presence of water can affect tablet quality and that in many cases there appears to be a critical water content, on either side of which tablet quality deteriorates (Khan et al, 1981; Ragnarsson and Sjogren, 1985; Armstrong et al., 1986). The last-mentioned showed, using anhydrous dextrose as a model, that there was a marked decrease in consolidation and tablet strength when the water content exceeded 9% w/w.

The aim of the present study was to further investigate the existence of a critical water content using dicalcium phosphate dihydrate as a model solid. This has extremely low aqueous solubility and so dissolution and subsequent recrystallisation resulting in crystal bridge formation would be avoided.

Materials and Methods

The 180–250 μm sieve fraction of directly compressible dicalcium phosphate dihydrate (Emcompress; Forum Chemicals, Reigate, U.K.) was used in this study.

* *Present address*: R.P. Scherer Ltd., Swindon, U.K.
** *Present address*: Wellcome Foundation, Beckenham, U.K.
Correspondence: N.A. Armstrong, Welsh School of Pharmacy, University of Wales Institute of Science and Technology, Cardiff, U.K.

Moisture induction and determination

Due to the low hygroscopicity of Emcompress, water could not be introduced by exposing the powders to atmospheres of known elevated humidity. Instead the powder was spread as a layer approximately 2 mm thick and sprayed with water using a Shandon laboratory pressurised pack (Shandon Southern Products, London, U.K.). Reproducible water contents were attainable by this technique.

The water content was determined by loss on drying at a pressure of 3 mm Hg at 103° C for one hour. Full details of the method are given elsewhere (Patel, 1986). All water contents are expressed in terms of the dry weight of the solid.

Compression

The powders were compressed on an eccentric press (Model F3, Manesty Machines, Liverpool, U.K.), fitted with a 12.5 mm die and flat-faced punches. The upper punch was fitted with four 350 Ω strain gauges forming a full Wheatstone bridge. A linear variable displacement transducer (Model 13284, Sangamo-Weston, Bognor Regis, U.K.) was fitted to the lower punch-holder and actuated by means of the moving upper punch. In this way, the separation of the punch faces throughout the compaction process could be measured. Amplified signals from the transducers were relayed via an analogue–digital converter into a BBC Acorn computer. Data were stored on magnetic disc and compressional parameters derived from them.

The die wall and punch faces were lubricated with a suspension of 5% w/w magnesium stearate in acetone. The powder was weighed in a humidity controlled environment and then introduced rapidly into the die cavity. The powder was compressed, the flywheel of the press arrested by means of a manually applied brake, and the tablet ejected from the die.

Measurement of compressional parameters

Tablet weight and dimensions were determined 24 h after ejection from the die for the evaluation of apparent density. Using the true density of the solid as measured by pycnometry (helium air pycnometer, Model 1302, Micromeritics, U.K.), the corresponding tablet porosities were calculated. Tablet porosity under compression (in situ porosity) was calculated from force and displacement data. The porosity was related to applied force by means of the Heckel equation (Heckel, 1961). The slopes of the Heckel plots were measured over the range 5–15 kN, and the yield forces, the reciprocals of the slopes, were calculated.

Elastic recovery was assessed by measuring the elastic expansion work on decompression that is the work carried out by the tablet on the punch as the latter is withdrawn from the die (Ragnarsson and Sjogren, 1983). Each compressional parameter reported in the present study represents the mean of 5 determinations with a coefficient of variation of not greater than 4% in any case.

Results and Discussion

The relationship between tablet apparent density and compression force was plotted at 9 water contents ranging from 0% to 10.8%. For each curve, verticals were erected on the force axis at 12, 18 and 24 kN, and the corresponding density noted for each water content. Fig. 1 shows the relationship between water content and apparent density at these 3 forces.

These curves have two noticeable features. Firstly, at all 3 compression forces, an increase in water content initially results in increased tablet density up to a maximum, beyond which a further increase in water content causes a reduction in densification. Secondly the critical water content corresponding to peak tablet density appears to be dependent on the applied force, with the maximum density tending towards lower water levels as the compression force is increased.

By fitting a quadratic equation to the curves in Fig. 1, estimates were obtained of the water levels corresponding to the 3 density maxima. Fig. 2 shows the relationship between in situ porosity and water content for Emcompress at the same 3 representative forces. The in situ porosities and porosities after ejection at the optimum water contents are given in Table 1.

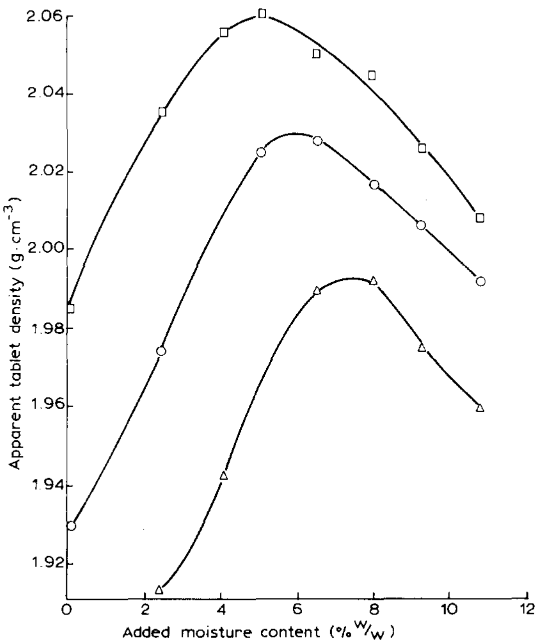

Fig. 1. The effect of added water on the apparent tablet density of Emcompress compressed at 3 forces. △, 12 kN; ○, 18 kN; □, 24 kN.

There appears to be a relationship between the minimum tablet porosity obtained under compression and the water content corresponding to maximum tablet density, implying that maximum consolidation occurs when the water present just fills

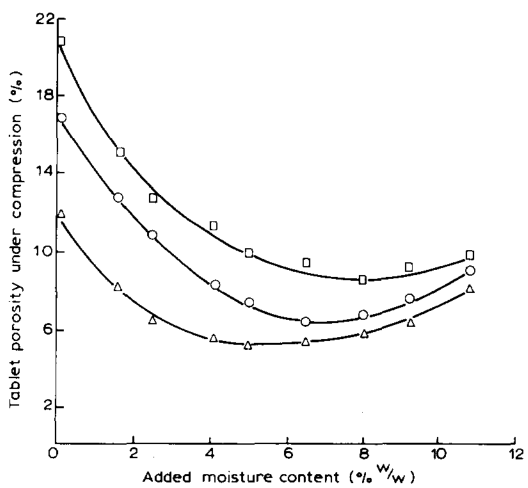

Fig. 2. The effect of added water on the in situ porosity of Emcompress tablets. Symbols as in Fig. 1.

TABLE 1

The relationship between applied force, optimum water content and tablet porosity

Applied force (kN)	Optimum water content (%)	Porosity after ejection (%)	Porosity in situ (%)
12	8.38	9.5	8.8
18	7.53	7.8	6.7
24	6.48	6.3	5.5

the pores within the tablet. A similar relationship has been previously observed for anhydrous dextrose (Armstrong et al., 1986). If the tablet porosity is equal to or less than the water content, then all the pores will be filled with water. Any excess water will be squeezed out and further consolidation prevented by hydrodynamic resistance. This theory would account for the force-dependence of the optimum water content (Table 1), and its tendency towards lower water levels as the compression force is increased (Figs. 1, 2). The higher the compression force, the lower will be the porosity and hence the lower the capacity of that tablet to accommodate water.

At levels below the optimum, moisture may assist consolidation by promoting interparticulate lubrication and by increasing the plasticity of the otherwise brittle Emcompress particles (Ragnarsson and Sjogren, 1985). This would have the effect of increasing force transmission from the upper punch to the lower punch and hence facilitating consolidation. Above the optimum water concentration, hydrodynamic resistance opposes further reduction in porosity with the optimum presumably representing a balance between the opposing effects.

In studies on granule formation, it has been reported that maximum granule strength and consolidation were obtained when the pores within the granules were just filled with water, i.e. granule porosity was equal to the water contents (Newitt and Conway-Jones, 1958; Newitt and Papadopoulos, 1959). These workers suggested that surface tension effects and capillary forces due to water were strongest in this condition. At water content less than or greater than the granule

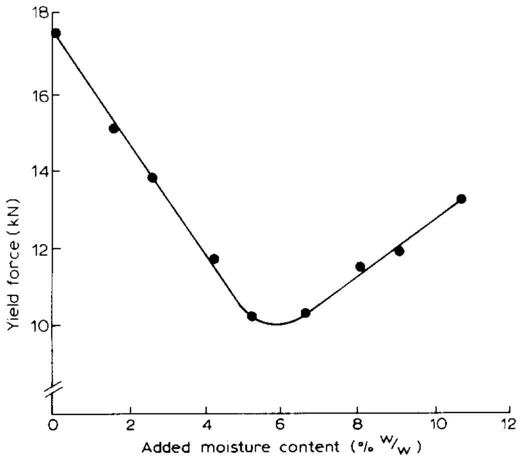

Fig. 3. The effect of water content on the yield force of Emcompress.

porosity, reduced granule strength and consolidation were obtained. Although the porosities of the granular systems examined by Newitt and coworkers were considerably greater than those of the tablets made in the present study, their theory to account for granule strength and consolidation also appears equally applicable to tablets.

To further assess the water-mediated effects on tablet consolidation, yield force values were calculated. Fig. 3 shows the effect of water content on yield force values of Emcompress derived from porosity data collected during compression. An increase in water content from 0% to 5% resulted in a reduction in yield force from 18 to 10 kN, i.e. consolidation is achieved more readily. This may be attributed to a combination of increased consolidation due to lubrication effects and a reduced resistance to particle deformation as the water content is increased (Khan et al., 1981). As the water content was increased to over 5%, a gradual increase in yield force was obtained. All pores are now full of water, and a further reduction in porosity can only be achieved by the expulsion of water from the porous structure of the tablet.

Water content also has an effect on the elasticity of the system. This can be shown by measuring the elastic work of expansion which occurs during the decompression stage of tablet production. Although the method will underestimate the total elastic recovery that takes place (Carless and Leigh, 1974), it was found that in a well-lubricated die, the elastic expansion work was representative of the total elastic recovery that took place (Patel, 1986).

Fig. 4 illustrates the variation in elastic decompression work with water content for Emcompress compressed at a force of 20 kN. It is apparent that a reduction in elastic recovery occurs upon increasing the water content from 0% to 6.5%, lending support to the theory that moisture may induce plasticity into the brittle Emcompress particles. At higher water contents, a significant increase in decompression work was obtained. Emcompress tablets containing 6.5% water have a porosity of approximately 6.0% when under a force of 20 kN. When the pores are completely filled with water, consolidation is reduced and weaker bonding between particles occurs. Hence the tablet is less able to withstand stresses imposed by the elastic recovery of the particles and increased elastic recovery of the tablet is observed. It was noted that both capping and punch-sticking became much more severe at higher water levels.

Thus the presence of water can exert a significant effect on the elastic recovery of Emcompress tablets and hence tablet quality. The tendency of tablets to cap may be minimised by the incorporation of an amount of water that is closely linked to the minimum porosity of the tablet when under

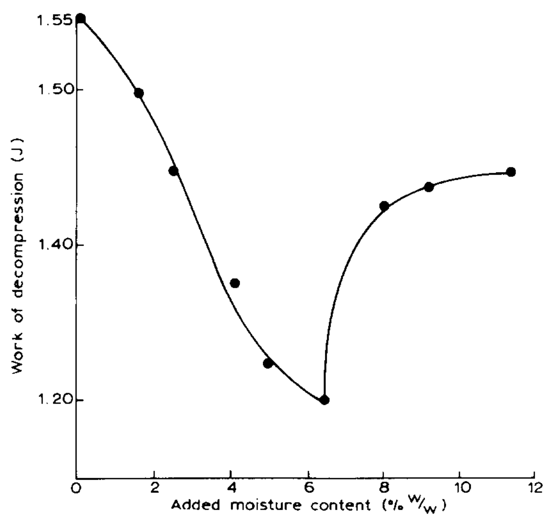

Fig. 4. The effect of added water upon the elastic decompression work of Emcompress compressed at 20 kN.

compression. Higher water levels may increase capping tendency. The increased elastic recovery must be partly responsible for reduced densification at higher water levels.

In conclusion, the presence of water in a powder to be compressed may assist or oppose tablet consolidation. Which effect predominates depends on the water content and the applied compressing force. By careful control of compression conditions, tablet quality may be optimised.

Acknowledgement

The award of a scholarship to A.N.P. by the Science and Engineering Research Council and the support of the Wellcome Foundation are gratefully acknowledged.

References

Armstrong, N.A., Patel, A.N. and Jones, T.M., The compressional properties of dextrose monohydrate and anhydrous dextrose of varying water contents. *Drug Dev. Ind. Pharm.*, 12 (1986) 1885–1902.

Carless, J.E. and Leigh, S., Compression characteristics of powders: radial die wall pressure transmission and density changes. *J. Pharm. Pharmacol.*, 26 (1974) 289–297.

Heckel, R.W., Density–pressure relationships in powder compaction. *Trans. Metall. Soc. AIME*, 221 (1961) 671–675.

Khan, K.A., Musikabhumma, P. and Warr, J.P., The effect of water content of microcrystalline cellulose on the compressional properties of some formulations. *Drug Dev. Ind. Pharm.*, 7 (1981) 525–528.

Newitt, D.M. and Conway-Jones, J.M., A contribution to the theory and practice of granulation. *Trans. Inst. Chem. Eng.*, 36 (1958) 422–439.

Newitt, D.M. and Papadopoulos, A.L., The mechanism of granule formation, *Proc. Fert. Soc.*, 55 (1959) 3–35.

Patel, A.N., *The Influence of Water on the Compressional Properties of Some Solids*, Ph. D. Thesis, University of Wales, 1986.

Ragnarsson, G. and Sjogren, J., Work of friction and net work during compaction. *J. Pharm. Pharmacol.*, 35 (1983) 201–204.

Ragnarsson, G. and Sjogren, J., Force–displacement measurements in tabletting. *J. Pharm. Pharmacol.*, 37 (1985) 145–150.