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Chemical Engineering Science 60 (2005) 3941–3947

Chemical Engineering Science

www.elsevier.com/locate/ces

The interrelationship between the compaction behaviour and the mechanical strength of pure pharmaceutical tablets

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Available online 15 April 2005

Abstract

This paper presents and analyses data obtained from the uniaxial compaction of pure pharmaceutical powders in terms of a number of mechanical properties, and correlates these data to some aspects of fracture mechanics. This includes seven different types of pharmaceutical drugs and excipients: alpha lactose, microcrystalline cellulose (Avicel PH 102), acetylsalicylic acid (Aspirin), dicalcium phosphate, magnesium carbonate, acetaminophen (Paracetamol) and starch. The powders were compacted to various ultimate normal stresses ranging between 25 and 246 MPa in an instrumented (force/displacement) single-ended axial compression in cylindrical die with planar punches. The results clearly demonstrate that, to some extent, the toughness of a tablet may be interpreted directly from some mechanical characteristics of its compliance response, i.e., the plastic work and the plasticity index, during the compaction process.

Keywords: Compaction; Fracture mechanics; Alpha lactose; Avicel PH102; Aspirin; Dicalcium phosphate; Magnesium carbonate; Paracetamol; Starch; Toughness; Compliance response; Plastic work; Plasticity index

1. Introduction

Many techniques for the densification of particles have been developed and optimised to suit particular material properties and product requirements. Powders, often in granular form, can be compacted within specifically shaped punches under high pressure to produce the desired compacted shape of sufficient mechanical integrity (Sonnergaard, 2000; Briscoe and Rough, 1998). The elucidation of the mechanisms of tabletting is of fundamental importance to a wide variety of commercial interests: for example in powder metallurgy, ceramic industry, explosive filling, catalyst manufacture and pharmaceutical tabletting (Train, 1957). However, the mechanical strength of the latter is usually expressed as either the force required to break tablets between two parallel platens (the crushing force imposed in the direction of the major axis) or the tensile stress, which develops perpendicular to a normally applied load (the tensile strength). For fully brittle compacts, the fracture develops in the direction of the applied normal load. However, tablets are invariably not fully brittle and the ductility can cause deviations from the ideal fracture pattern (Newton et al., 1971). The tensile strength of tablets can be explained using the principles of fracture mechanics and depends upon the internal distribution of flaws and cracks as well as the same features on the surface. This appears at first contradictory, because the literature also state that the strength of a compact is a result of solid–solid adhesion between the single powder particles (Kendall, 1988). However, adhesion and friction are also physical properties, which may be explained on the basis of fracture mechanics principles. The action of adhesion forces is in fact a process of failure in mode I (Maugis and Barquins, 1978; Greenwood and Johnson, 1981, Kendall, 1994a,b).

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0009-2509/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ces.2005.02.027

2. Materials and experimental methods

2.1. Material

Seven different kinds of excipients and drugs, as tabulated in Table 1, were investigated for this paper.

2.2. Preparation

The mass of each tablet was selected to be ca. 0.001 kg, and the powder for each tablet was weighed using a Sartorius electronic balance, Model MC1 (Sartourius AG, Goettingen, Germany), with the accuracy range of ±0.01 mg, and poured into a hardened stainless steel cylindrical die 16 mm in diameter, using a plastic funnel with a large tube diameter to facilitate the flowability of the powder (stage I in Fig. 1).

2.3. Uniaxial compaction

The tablets were uniaxially compacted, between a mirror-polished platen and a single acting upper punch, in a cylindrical 16-mm diameter hardened stainless steel die manufactured by Specac, UK (stage II in Fig. 1). The compactions were carried out using a commercial universal testing machine (Lloyds EZ 50, UK) with nominal load and displacement resolutions of 0.02% and 10 μm, respectively, at a cross-head speed of 0.1 mm/s for loading and 0.0167 mm/s for unloading (stage III in Fig. 1). The applied force and the cross-head displacement were recorded by a compatible computer software program, termed Nexygen Ondio (Lloyd instruments). All the tablets were compacted to an ultimate imposed normal stress ranging between 25 and 246 MPa. The compacted tablets were ejected from the die after the removal of the lower platen (stage III in Fig. 1) at the end of each run, and a force was applied to the upper punch using the Lloyds testing machine with a constant cross-head speed of 0.083 mm/s (stage IV in Fig. 1). The dies were not lubricated.

2.4. Brazilian test

As the pharmaceutical drugs, in general, are sensitive to ambient humidity and absorbed moisture, the tablets were dried in a high vacuum oven for a minimum duration of 24 h and at 60 °C temperature. It Suffices to say that the melting point of the materials used in the current study is in excess of 120 °C. The Brazilian style compression was carried out with Lloyds EZ 50 using a 1 kN transducer. Each tablet was fractured diametrically between two parallel platens at a cross-head speed of 0.0116 mm/s, utilising two square pieces of cardboard, 0.25 mm in thickness, as "the padding" to insure an even distribution of stress and consequently to acquire a mode I failure (tension mode). To obtain a compliance equation for these pieces of cardboard, 24 pieces of the cardboard were cut into square geometry and mounted on a block of aluminium. Using Lloyds EZ 50 UTM, an ultimate reaction force of 0.9 kN, at a cross-head velocity of 0.01 mm/min, was applied and the resultant loading and unloading curve was plotted. A mathematical software (Origin) was utilised to fit a model to the loading curve. The following equation was acquired from the curve

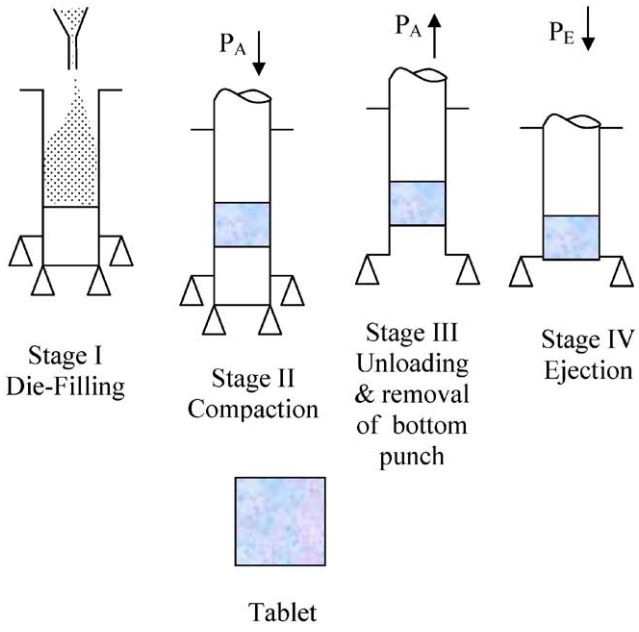

Fig. 1. Schematic representation of the major manufacturing stages for the unaxial die pressing method. P_A and P_E represent applied and ejection stresses, respectively.

Table 1
Materials utilised in the experimental studies

Material	Synonym	Tradename	Manufacturer	Batch no.
Microcrystalline cellulose		Avicel PH 102	FMC, USA	7007C
Lactose monohydrate	Alpha lactose	Granulac	Meggle, Germany	L0004A4172
Dicalcium phosphate dihydrate	Calcium phosphate	Calipharm	Albright & Wilson, UK	420961
Pregelatinised maize starch	Modified corn starch	Starch 1500	Colorcon, USA	IN500658
Magnesium carbonate			Sigma-Aldrich Cheme, Germany	67H1525
Acetaminophen	Paracetamol		Sigma-Aldrich Cheme, Germany	107H0332
Acetylsalicylic acid	Aspirin		Sigma-Aldrich Cheme, Germany	77H0519