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RESEARCH PAPER

Tensile Strength and Bonding in Compacts: A Comparison of Diametral Compression and Three-Point Bending for Plastically Deforming Materials

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ABSTRACT

The tensile strength of tablets is frequently used as a measure of the bonding achieved during compaction. Tablets from two plastically deforming materials and one brittle material have been subjected to tensile strength testing using diametral compression and three-point bending. The plastically deforming materials exhibited marked inhomogeneities, with the surfaces of the tablets considerably more compact than the inner material. The results from the two tests were different, with the three-point bending test giving higher results for tensile strength. The rate of change of tensile strength with overall tablet porosity was, however, the same for the two tests. Diametral compression would thus appear to give a reasonable estimate of bonding despite the non-homogenous nature of tablets prepared from plastically deforming materials.

Key Words: *Bonding; Diametral compression; Tensile strength; Three-point bending*

INTRODUCTION

Studies on the bonding forces pertaining in tablets usually make the assumption that the mechanical strength of a tablet is directly related to the bonding achieved during compaction.[1,2] Tablets are not homogenous and the heterogeneity can be exacerbated if the material being compacted deforms plastically. Earlier studies by Train and Lewis[3] showed that a compact of lead shot was held together by a

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"skin" produced by the high shear at the wall of the die. Johansson et al.[4] compacted pellets of microcrystalline cellulose and found, by examination using scanning electron microscopy (SEM), that discrete pellets could be distinguished in the compact whereas pellets at the surface were flattened and considerably deformed. In systems such as these, the measured mechanical strength may not truly reflect the bonding achieved during compaction.

The tensile strength of a tablet is usually measured by diametral compression. Under correct conditions of loading, the diameter of the tablet is subject to a uniform tensile stress which causes failure. Despite the tensile stress being uniform across the diameter, it is frequently found that the initiation of the fracture is in the center of the compact and that the crack formed does not extend completely to the outer diameter. The measured tensile strength may thus be an indicator of bonding conditions in the center of the tablet.

An alternative measure of tensile strength can be obtained using a three-point bending test. Here, the tablet is subjected to a bending stress created by a central knife edge pressing on the tablet supported on two outer knife edges. Fracture commences at the surface and the tensile strength can be calculated from a knowledge of the load to cause failure and the distance apart of the lower edges.

For plastically deforming materials as described above, it would be expected that the two measurements would yield different results as the site of crack propagation is different in the two tests. If, however, the change in strength as determined by the two methods with, for example, changes in compaction pressure or porosity is equivalent, it may be argued that diametral compression is a reasonable reflection of the bonding achieved during compaction, despite the inhomogeneities of the compact.

This article reports the results of a study in which the tensile strength of tablets prepared from two plastically deforming materials and one brittle material are compared by the two methods. The tablets are also subject to friability testing which is also a surface property.

MATERIALS AND METHODS

Materials

Polyvinyl chloride (PVC) (Evipol, European Vinyl Corporation, Runcorn, UK) and microcrystalline cellulose (Emcocel LP200, Penwest, Guilford, UK) were chosen as plastically deforming materials. Lactose [Pharmatose 200M, DMV (Taddington, UK) Ltd.] was used as a material deforming mainly by fragmentation. Magnesium stearate was from BDH, Poole, UK. All materials were used as received.

Preparation of Tablets

Tablets of the individual materials were prepared using a single punch tablet machine (Manesty F3, Manesty Ltd., Liverpool, UK) fitted with a circular, 1.27-cm diameter flat-faced punch and die set and operated at machine speed. The tablet weights were adjusted to give tablets of approximately 0.3 cm thickness. Polyvinyl chloride and microcrystalline cellulose were compressed unlubricated. The lactose tablets contained 0.5% magnesium stearate.

Several batches of tablets of each material were prepared at different pressure settings. The actual pressures used were not recorded as the aim was to compare the tablet strength at different porosities.

Tablet Properties

Overall tablet porosities were calculated from the tablet dimensions and the true particle density of the material (AccuPyc 1330, Micromeritics, Norcross, GA). Tensile strength using diametral compression was determined by measuring the load to fracture the compacts across the diameter using a compression testing machine (Howden Universal Testing Machine, R.P. Howden, Leamington Spa, UK) at 0.1 cm/min. Tensile strength was calculated from the formula:

$$\text{Tensile strength} = \frac{2P}{\pi DT}$$

where P is the breaking load, D is the tablet diameter, and T is its thickness. Tensile strength from three-point loading was measured using the same testing machine equipped with a rig supporting the tablet on two knife edges, 11.23 mm apart, with a top platen fitted with a central knife edge applying the force to the tablet. The speed of the crosshead was 0.1 cm/min. Tensile strength was calculated from:

$$\text{Tensile strength} = \frac{3PL}{2DT^2}$$

where L is the distance between the supports.

The single knife edge was always located on the surface of the tablet that had been adjacent to the moving punch.

The results from the two methods for the determination of tensile strength are the mean of six determinations and gave values for the coefficient of variation for each set of results of less than 3%.

Friability was determined using a Roche Friabilitor (Erweka Gmbh, Offenbach, Germany). Tablets (10 g) were rotated at 20 rpm for 10 min. The dust from the tablets was removed by shaking on a 250-μm sieve and the tablets re-weighed. The friability (%) was defined as the remaining weight/original weight × 100.

Scanning electron photomicrographs of the tablets were taken using a Cambridge Stereoscan (Model 360, Cambridge Scientific Instruments, Cambridge, UK). The specimens were mounted on circular aluminum stubs and coated with gold prior to observation.

RESULTS AND DISCUSSION

Figure 1a–c shows sections through the fracture surfaces of tablets prepared from PVC (17% porosity), microcrystalline cellulose (34% porosity), and lactose (18% porosity). Denser upper and lower regions can most clearly be seen in the PVC tablets. They are also present in microcrystalline cellulose tablets and absent in lactose tablets. Similar gradations of porosity occurred for tablets made at different pressures. Figures 2 and 3 show the relationships between overall tablet porosity and tensile strength or friability for the three materials. The tensile strength values as measured by the two methods are different for all three materials. In each case, the strength measured by three-point bending gives the higher value. It is tempting to suggest that this is due to the greater degree of compaction at the surface, although even for lactose, where the inhomogeneities in the tablet are less pronounced, the results are markedly different. These results are perhaps not surprising considering the different nature of the two tests. They are also in keeping with the study by Wright[5] comparing the tensile strength of concrete as assessed by three different methods. Wright found that the results from a three-point loading test were higher than those obtained from a diametral compression test and argued, theoretically, that this would be expected. It is perhaps surprising,

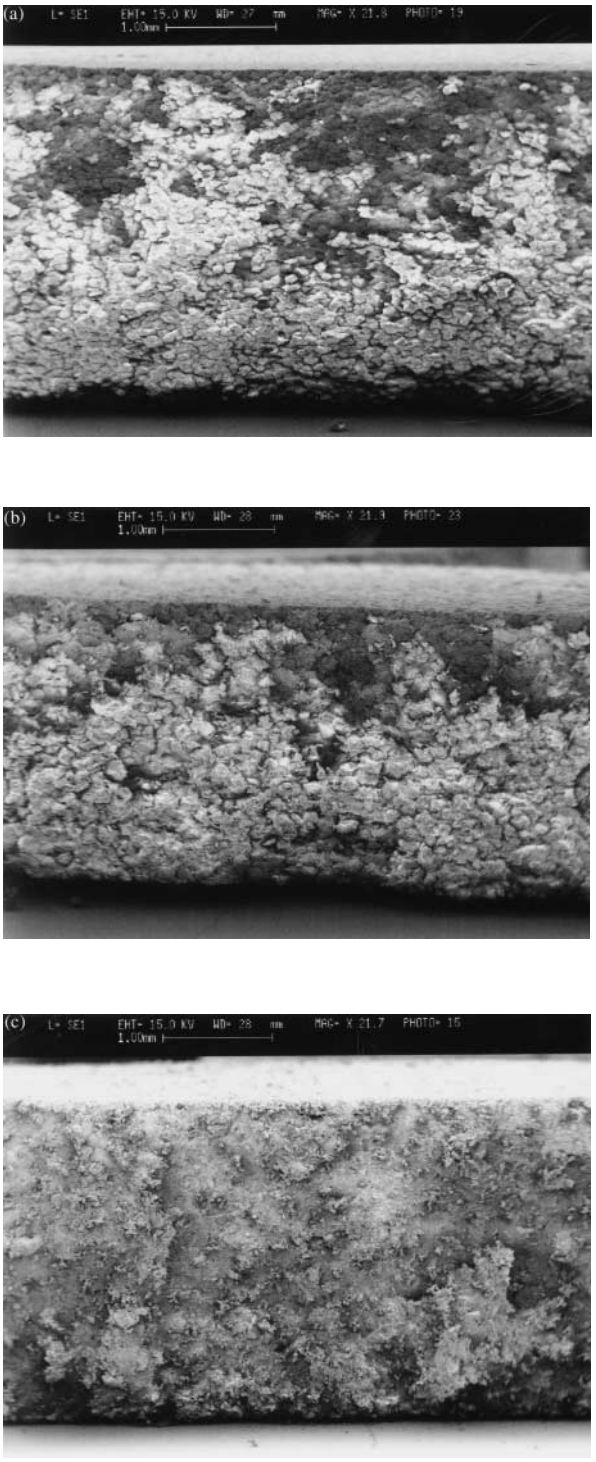

Figure 1. Scanning electron photomicrographs of cross-sections through the tablets: (a) PVC; (b) microcrystalline cellulose; (c) lactose.

therefore, that David and Augsburger[6] found good agreement between the two tests using tablets of lactose, starch, and microcrystalline cellulose, although they did use a different equation for the calculation of tensile strength.

The weight loss from the tablets subjected to friability testing is in the order lactose > PVP > microcrystalline cellulose. This correlates directly with the tensile strength results. The lower friabilities of the plastically deforming materials may result from a combination of the inherently stronger bonding achieved and the more compact surface layers.

The relationship between tensile strength and overall tablet porosity can be expressed by the

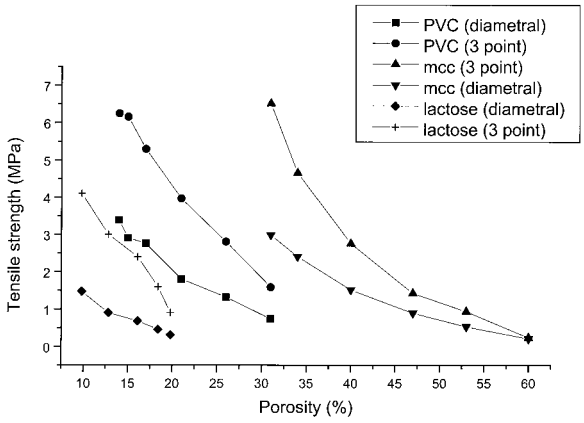

Figure 2. The relationship between tablet porosity and tensile strength for the three materials determined by diametral compression and three-point bending.

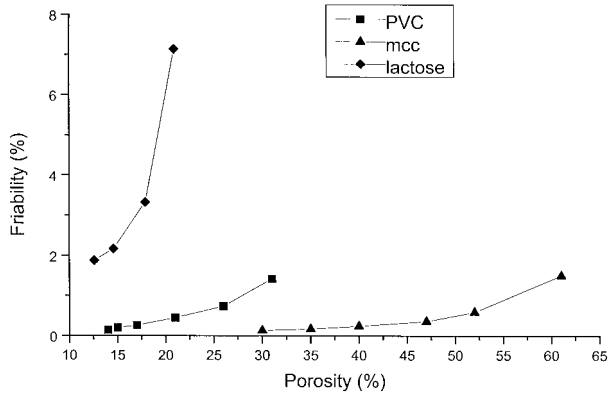

Figure 3. The relationship between tablet friability and porosity for the three materials.

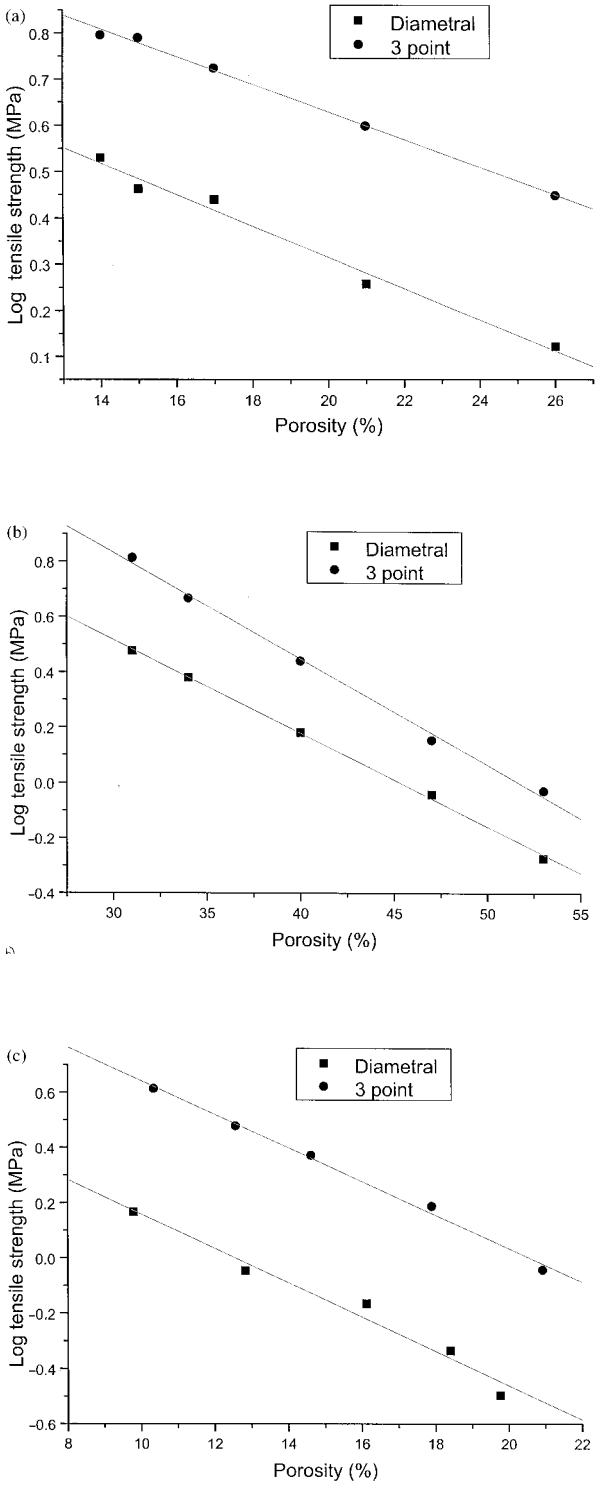

Figure 4. The relationship between log tensile strength, as determined by diametral compression and three-point bending, and tablet porosity: (a) PVC; (b) microcrystalline cellulose; (c) lactose.

Table 1

Parameters of the Regression Lines for the Relationship Between Log Tensile Strength and Porosity

	Regression Coefficient	Intercept	Correlation Coefficient
Diametral PVC	−0.0338	0.992	−0.992
Three-point PVC	−0.0299	1.227	−0.998
Diametral MCC	−0.0337	1.527	−0.999
Three-point MCC	−0.0383	1.982	0.998
Diametral Lactose	−0.620	0.780	−0.986
Three-point Lactose	−0.607	1.249	−0.997

equation:

$$\text{Tensile strength} = S_o e^{-bp}$$

where S_o and b are constants and p is the porosity.[7,8] The results from the two tests for the three materials, plotted in this manner, are shown in Figure 4a–c. What is striking is that, despite the difference in the results for the two tests, the rate of change of tensile strength with porosity is the same. The parameters for the regression lines are given in Table 1. Comparison of the regression coefficients for each of the three materials shows they are not significantly different ($p > 0.05$).

The two tensile strength tests thus show parallel changes in strength with overall porosity despite the inhomogeneities present in the compacts and the different loading conditions of the two tests. It is thus reasonable to conclude that if the strength of a tablet is a valid method of assessing bonding, then the diametral compression test can be used despite the heterogeneous nature of compacts produced from plastically deforming materials.

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