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DETERMINATION OF MECHANICAL STRENGTH OF SAME MATERIAL DOUBLE-LAYER RECTANGULAR TABLETS

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ABSTRACT

The mechanical strength of same material composite beams of Avicel PH102, Starch 1500 and Emcompress were assessed by three-point bending test. To provide an improved method of comparing the strength of the tablets, the tensile strength of the specimens was calculated by equations based on stress analysis. Increasing the compaction pressure led to decrease of the porosity of the compacted tablets while the overall mass of the composite tablets were kept constant. Meanwhile, the values of fracture load and strengths (including tensile and shear) raised by increasing the compaction pressure. However, when the lower layer was compacted twice, the value of tensile stress of the lower layer was more than its value in a single compacted tablet with the same material. This observation was attributed to the extent of the reduction of porosity during compaction of the single tablets which raised in their tensile strength values.

Key words: Three-point bending test, Double-layer rectangular tablets, Avicel PH102, Emcompress, Starch 1500

INTRODUCTION

Beams of two or more materials are historically referred to composite beams. A beam made of the two or more separate materials where the materials occupy a definite position on the cross-section of the beam is a specific type of composite beam. The failure of brittle materials is principally due to crack propagation, as a result of the effect of tensile stress. Thus, it is expected that the fracture of a tablet will initiate from the lower surface that is subjected to a high tensile stress. The compressive stress on the upper layer is not an important factor, even if its value exceeds the value of tensile stress. Therefore, it is reasonable to consider tensile stress of the lower layer as a criterion for the inspection of failure. The theory associated with normal stress in beams based on flexure stress formula has been defined (1,2). The beam of Figure 1 is loaded to produce pure bending along the section of the concentrated load. Pure bending occurs when the shear is zero. The deformation assumption is due to the pure bending. For the beam that is subjected to pure bending, as shown in Fig. 1;b, the lines AD, BE, and CF are straight lines before and after deformation. The deformation occurs when the top surface of the beam is in compression and the bottom surface is in tensi There is a line along the longitudinal axis of beam that does not change in length. Actually represents a surface passing through the thick of the beam. This line, which separates compression zone from the tension zone, is ca the neutral axis. A beam section subjected to transverse shear and bending is shown in Fig. where the shear causes some distortion of the cr section. Primary bending causes the deformation the beam, and the deformation caused by she usually neglected. However, the presence of stress cannot always be neglected. The n element of Figure 1c illustrates the action shear strain, γ_{xy}. It follows that a shear stres also exists. The assumption of pure bending to the existence of an axial strain, as shown t material element in Figure 1b. The flexure f is based on the deformation that occurs wh bending is assumed. In the same material layer tablets, the neutral axes and centred ax located on the same line. The axial tensile str of double layer compacts prepared from a compressed layer with varying surface rough

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and a layer of material in powdered form has been studied for some materials (3). The materials consolidate mainly by plastic deformation such as Sodium chloride, Avicel PH101 and STA-RX 1500 were all very sensitive to a decrease in the surface roughness of the precompressed layer of the double layer tablet. The fragmenting materials lactose, sucrose and emcompress were relatively unaffected by the pretreatment of the first layer. It was concluded that a decrease in the surface roughness of the first layer of the double-layer tablet resulted in a marked decrease in inter-particular attraction between the two layers for materials undergoing volume reduction mainly by plastic deformation, but did not substantially influence these attractions for easily fragmenting materials. The young's modulus of 15 pharmaceutical excipient powders compressed in the shape of rectangular beam specimens using four-point beam bending technique has been studied (4). It has been shown that a decrease in young's modulus with increasing porosity was seen for all materials, with a more rapid decrease at lower porosity. The mechanical properties of elongated tablets of different thickness which were prepared at a range of pressures with surfaces that were flat or curved has been determined by application of a flexure test (5). The results showed that the tensile strength of beam-shaped tablets depends on their dimensions. This could be due to changes of the structure within the specimen during the formation process and there were clear indications that tablet porosity for equivalent compaction pressures was not equal. The objective of this work was to determine the mechanical strength of same material composite beams or double-layer tablets composed of Avicel PH102, Emcompress and Starch 1500 under application of bending theory.

MATERIALS AND METHODS

Two different size fractions of 90 μm and 250 μm of powders were used. Details of material suppliers and density have been shown in table 1. A set of upper and lower punches in a rectangular cross-section with dimensions of width (b=10 mm), length (L=25 mm) and various thickness were used. A die of same dimensions was used to manufacture all the tablets on the Instron physical testing machine (Floor model No.TT, Instron). Five different pressures ranging from 18-80MPa were used to manufacture tablets at a crosshead movement rate of 1 mm/minute. The same compaction pressure was used to compact the upper and lower layers of the composite tablets. As the rectangular specimen of two materials was subjected to test apparatus, its tensile strength was calculated from the load at fracture. The tablet was supported at two fixed points and an increasing load was applied on the center of the tablet until it fractures (Fig.1a). The tensile strength (σ_f) calculation was carried out according to the following equation (6); [$\sigma_f = 3FL/2bd^2$] where b and d are the width, and thickness of the rectangular cross-section, F is the fracture load and L is the distance between the supports of the test apparatus. The flexure shear strength (τ) was calculated according to the equation that was used for flat-faced rectangular tablets (7), namely; [$\tau = 3F/4bd$]. All tablets after manufacturing were stored in sealed containers for 7 days at room temperature. They were then individually subjected to three-point flexural bending test such that the force to the middle top surface of the tablet by means of CT-40 tablet tester was at a platen movement of 1 mm/minute. The value of breaking load for fracturing of each tablet was obtained for further strength calculation. All reported strengths were based on 10 determinations for a given pressure of compaction. The porosity of the tablets was determined by calculation of their packing fraction. The porosity is linked to the bulk density of the tablets. Since the mass and volume for each material in the double-layer rectangular tablets were similar, the porosity determination was calculated by the volume occupied by the powders as for single rectangular tablets, i.e. [V_{bulk}=b.d.L], where b, d and L are width, thickness and length of the beam, respectively. The most widely used indices for closeness of packing are those of bulk density and the related characteristics packing fraction and fractional voidage (8). Bulk density, ρ_B, is a characteristic of a powder rather than individual particles and is given by the mass, M, of powder occupying a known volume, V, according to the relationship; [ρ_B= M/V (gcm^{-3})]. Since the powder contains inter-particle pores or voids, the bulk density of a powder

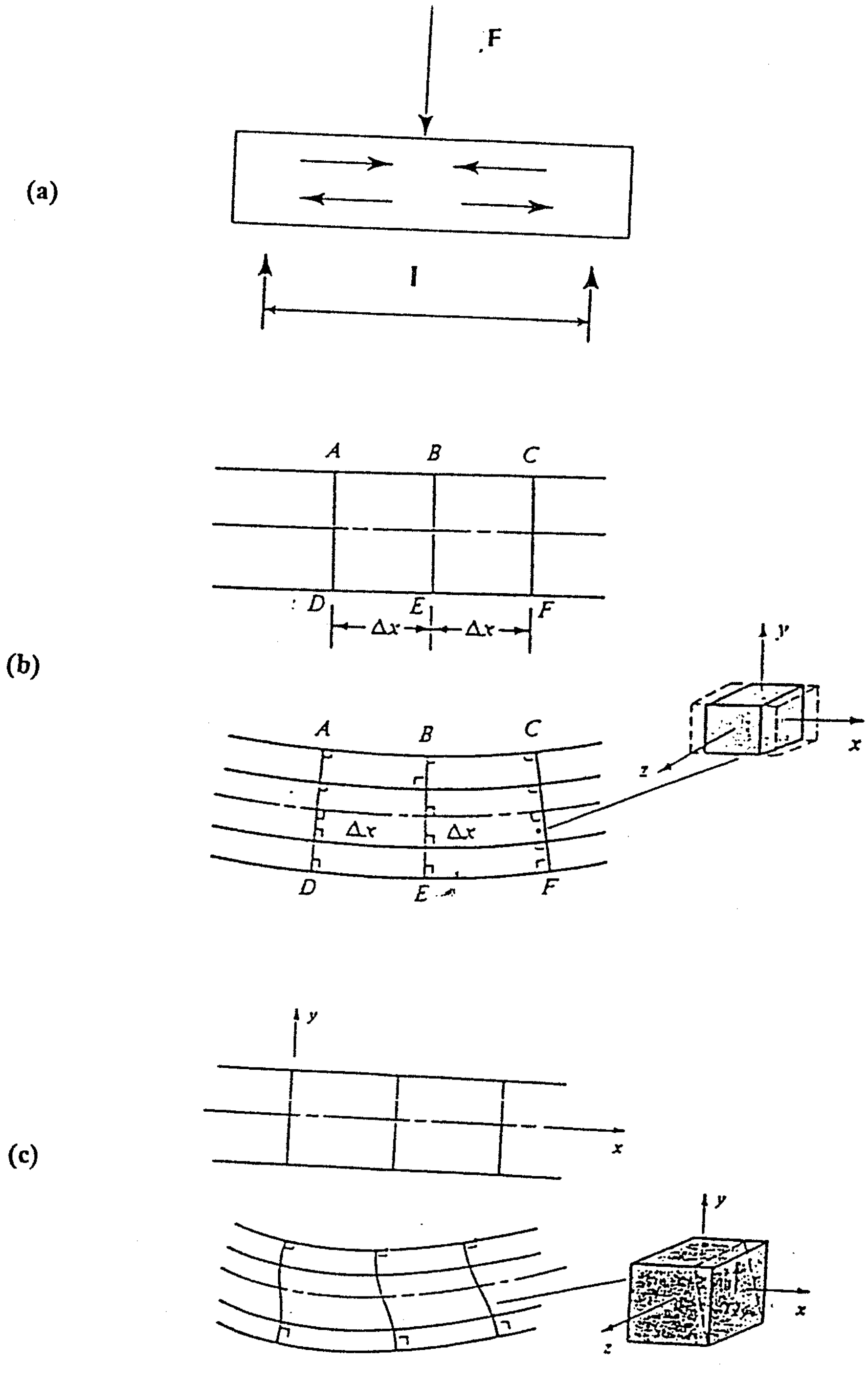

Fig. 1. a: beam loading to produce bending
b: section subjected to pure bending
c : section subjected to transverse shear and bending
F is fracture load, and I is the distance between two supports.

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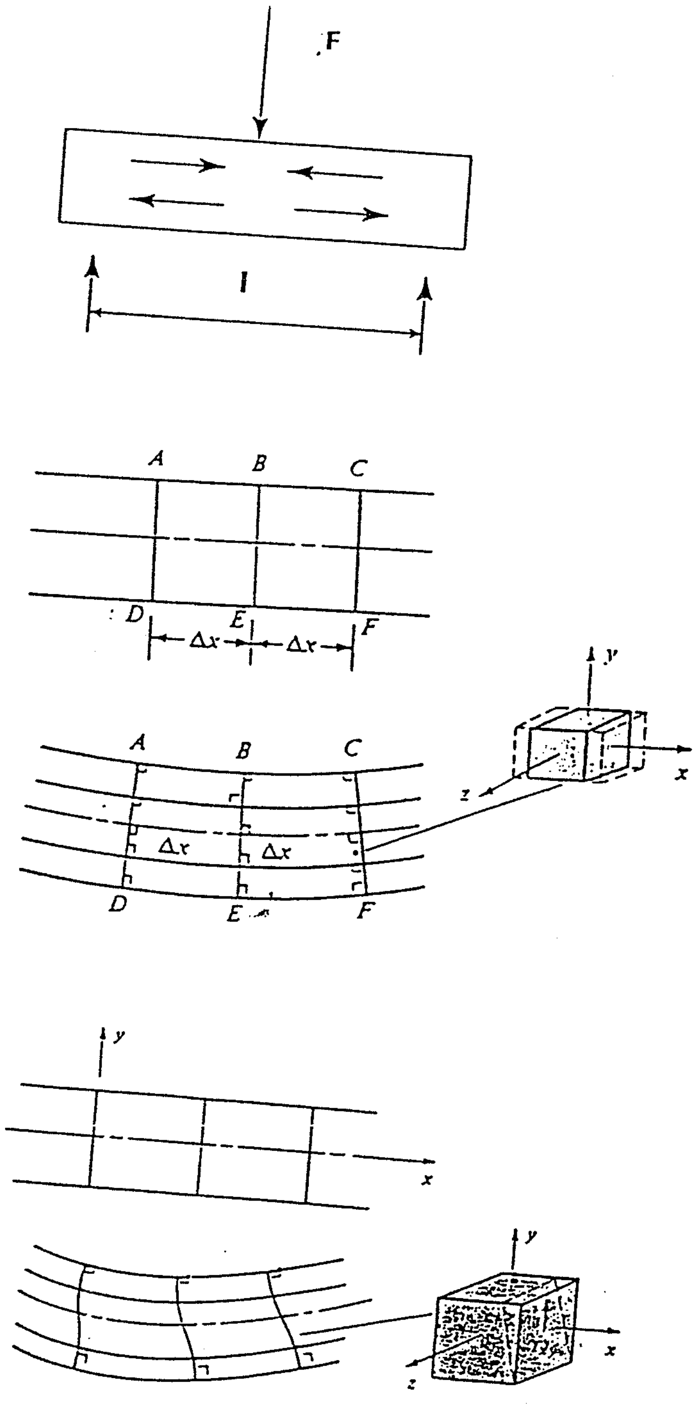
(a)

(b)

(c)



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s always less than the true density of its component particles. The bulk density is directly proportional to true density, i.e. [bulk density ∝ true density] or [bulk density=K. true density], where K is the packing fraction (ρ_{ff}). The packing fraction can be calculated by the equation [$\rho_{ff}= \rho_{bulk}/\rho_p$]. The bed porosity or fractional voidage of tablets are calculated by the formula; [1-K= porosity]. The voids ratio provides information about the stability of the powder mass.

RESULTS AND DISCUSSION

Consolidation of powders, which occurs through a complex process including particle deformation and fragmentation, leads to closer packing. Thus, for a given compaction pressure, there are different porosity, tensile and shear strengths.

Data showing tensile strength as a function of compaction pressure for double-layer compacts are presented in Table 2;a,b,c. Considering two different size fractions for each material the values of strengths, fracture load, porosity and thickness were low for the larger one (250 mm). However, the range of changes was considerable for Avicel PH102 and there were only slight changes for Emcompress and Starch 1500. By examination of the failure of the circular tablets subjected to diametric compression, it has been reported that the tablet materials must be six times stronger in shear than in tension for achieving ideal tensile failure (9). However the rate of changes for σ_f/τ in the present study was more than 8 times for each material, indicating that all tablets failed in tension rather than by shearing forces. Depending on the material, the thickness was different for a given compaction pressure of tablets, in the way that; "Avicel PH102>Starch 1500>Emcompress" at the lower compaction pressure, and "Emcompress>Starch 1500>Avicel PH102" at the higher compaction pressure. Also the mass of the tablets varied according to their densities, i.e.:

"Emcompress>Avicel PH102>Starch 1500".

The load required to fracture the tablets varied according to the characteristics of materials as follows;

"Avicel PH102>Emcompress>Starch1500". Meanwhile, the rate of porosity changes due to the increase in the compaction pressure varied in different tablets, in the way that; "Avicel PH102>Starch 1500>Emcompress".

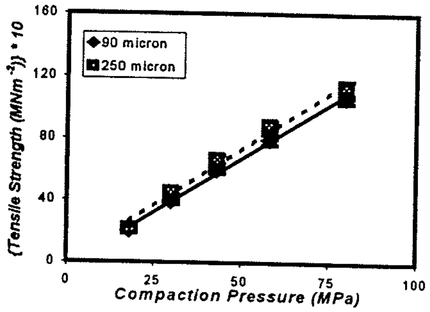

Fig. 2. Tensile strength as a function of compaction pressure for two size fraction of double layer (composite) tablets of Avicel PH102. Y_{90}=1.3869x-2.789, R^2=0.9958; Y_{250}=1.4603x+0.061; R^2= 0.9863.

It was observed that the value of tensile stress of the lower layer was more than its value in single compacted tablet of the same material (Table 3; a, b). It was assumed that in the composite tablet the lower layer was twice compacted and as a result the porosity of the double-layer tablets (Table 3b) was apparently lower than the single compacted tablet (Table 3a), as it is clearly shown by the same material starch 1500 composite tablets. Thus, the value of tensile strength has been raised for composite tablets. It was also revealed that there was a relationship between tensile strength and compaction pressure in the same material composite beams (Fig 2).

Comparison of the results obtained following treatment of both surfaces of composite tablets showed that the behaviour of each material was different in compression rather than in tension, since values of compressive stress (σ_c) and tensile stress (σ_f) obtained from both tests was different. It was also observed that the value of critical stresses in tension was higher than that in compression.

Table 1. Details of material suppliers and density

Material	Grade	Supplier	Density	CV% (n=5)
Avicel PH102	Pharmaceutical	FMC, USA	1.55	0.58
Starch 1500	Pregelatinized Starch (NF)	Colorcon Inc, USA	1.475	0.23
Emcompress		Forum Chemicals Ltd	2.32	0.39

Table 2. Tensile strength as a function of compaction pressure for double-layer compacts of: a) Emcompress-Emcompress, b) Starch 1500-Starch 1500, and c) Avicel PH102-Avicel PH102

(a)

CP (Mpa)	Micron	D (cm)	Force (kg)	Porosity	σ_f (MNm^{-2})	τ (MNm^{-2})
18	90	0.396	0.152	0.347	0.262	0.029
	250	0.385	0.100	0.329	0.182	0.019
30	90	0.374	0.270	0.308	0.521	0.054
	250	0.359	0.214	0.281	0.447	0.045
43	90	0.360	0.347	0.282	0.721	0.072
	250	0.346	0.303	0.282	0.684	0.066
58	90	0.348	0.437	0.256	0.976	0.094
	250	0.338	0.390	0.234	0.921	0.086
80	90	0.338	0.534	0.235	1.260	0.118
	250	0.326	0.509	0.208	1.288	0.117

(b)

18	90	0.410	0.112	0.366	0.179	0.020
	250	0.409	0.074	0.363	0.179	0.014
30	90	0.373	0.221	0.302	0.430	0.044
	250	0.377	0.160	0.310	0.304	0.032
43	90	0.351	0.321	0.261	0.702	0.069
	250	0.348	0.260	0.252	0.280	0.056
58	90	0.329	0.401	0.210	0.0997	0.091
	250	0.962	0.349	0.210	0.870	0.080
80	90	0.316	0.520	0.177	1.406	0.123
	250	0.310	0.427	0.158	1.201	0.103

(c)

18	90	0.448	1.605	0.424	2.155	0.269
	250	0.438	1.420	0.412	1.995	0.243
30	90	0.379	2.423	0.319	4.549	0.479
	250	0.382	2.110	0.326	3.893	0.414
43	90	0.351	3.035	0.264	6.654	0.648
	250	0.349	2.678	0.260	6.654	0.575
58	90	0.328	3.531	0.214	8.840	0.807
	250	0.325	3.115	0.208	7.938	0.719
80	90	0.309	3.989	0.165	11.274	0.968
	250	0.306	3.681	0.155	10.600	0.902

Table 3. Tensile strength and porosity of rectangular tablets of Emcompress, Starch 1500 and Avicel PH10 with 0.3 cm thickness

a) Single beam-shaped tablets

C.P.	Emcompress		Starch 1500		Avicel PH102	
Mpa	Porosity	σ_t	Porosity	σ_t	Porosity	σ_t
18	0.333	1.064	0.390	0.842	0.493	15.360
30	0.294	2.954	0.330	2.194	0.363	38.917
43	0.264	5.053	0.270	4.219	0.334	61.718
58	0.237	7.917	0.230	7.430	0.232	79.570
80	0.223	11.989	0.160	10.631	-	-

b) Same material double-layer beam-shaped tablets

C.	Emcompress/Emcompress		Starch/Starch		Avicel/Avicel	
Mpa	Porosity	σ_t	Porosity	σ_t	Porosity	σ_t
18	0.329	1.821	0.363	1.795	0.412	19.950
30	0.281	4.473	0.310	3.038	0.326	38.930
43	0.282	6.843	0.252	5.805	0.260	66.541
58	0.234	9.208	0.210	8.701	0.208	79.385
80	0.208	12.879	0.158	12.006	0.155	105.999

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