DETERMINATION OF MECHANICAL STRENGTH OF DIFFERENT MATERIAL DOUBLE-LAYER RECTANGULAR TABLETS.

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ABSTRACT

The mechanical strength of different material composite beams were assessed. All tablets were subjected to three-point bending test. For the preparation of tablets, the material of the lower layer was initially put in the die and compacted by a certain pressure. The second material was then put upon the first layer. Modulus of elasticity of the selected materials were used to interpret the behaviour of the top and bottom layers of the different materials composite tablets. Determination of the strength at the highest and lowest point of different material composite beams, showed that if the material with higher modulus of elasticity was placed at the lower layer, the value of compressive strength (σ_c) obtained from exerting fracture load at the higher point, was more than the value obtained at the lower point (i.e. tensile strength, σ_f). On the other hand, if the material of higher modulus of elasticity E, was located at the top surface, the stress value at the lower layer (σ_f) was more than its value at the higher layer (i.e. σ_c). The range of σ_c/σ_f was 1/3, if number of components (n) was much more than one. Inversely, when 'n' was less than 1, the value for σ_c/σ_f was near 3.

Keywords: Flexure test (three-point bending test), Double-layer rectangular tablets (composite beams), Starch 1500/Avicel PH102, Emcompress/Avicel PH102, Emcompress/Starch 1500.

INTRODUCTION.

The analysis of a beam of two different elastic materials has been reported previously (1). A bi-material beam is a beam made of two materials bounded together with the cross-sectional of Figure 1 (a, b, c, d). The beam is assumed to be subjected to the pure bending and hence, assumption of stresses caused by bending is valid. Essentially, plain sections normal to axis of the beam prior to bending of the beam remain plain after bending. The result is that the strain varies linearly with the cross-section and is zero at the normal axis.

The failure of brittle materials is principally due to the crack propagation which is induced from the lower surface which is subjected to a high tensile stress. Young's modulus, which is independent of beam thickness (2) and is related to porosity (3), is a measure of the stiffness of a material and it can be estimated by measurement of the slop of the stress-strain curve in the elastic region. The axial tensile strength of the double layer compacts prepared from a precompressed layer with varying surface roughness and a layer of material in powdered form for some tableting excipients (4) suggests that a high fragmentation tendency of tableting compounds and excipients will facilitate the formation of mechanically strong multi-layer tablets.

In the composite tablets of two different materials, σ_c is the maximum compressive stress exerted on the top surface of the beam and σ_f is the maximum tensile stress on the lower surface of the tablet during strength testing. These maximum values are different for a given material at a given compaction pressure, indicating different compressive and tensile stresses of the ingredients of the two-layer tablets as their modulus of elasticity are different.

In manufacturing different material double-layer tablets, the material of the lower layer was initially put in the die and was compacted by a certain pressure. The second material was then put upon the first layer and was compacted in the same manner as described for the first layer. It is assumed that the material of the lower layer has been compacted twice by the same pressure (i.e. double-compacted). Thus, it is expected that the porosity of the material in the lower layer would be different from that of a single compacted tablet of the same material. This, in turn, will probably makes tensile strength of these materials different.

The aim of this work was application of bending theory for the analysis of mechanical strength of different material double-layer tablets.

MATERIALS AND METHODS.

A size fractions of 125-180 μm of powders of Starch 1500, Emcompress and Avicel PH102 were used. The modulus of elasticity of each material were chosen from the references shown in table 1. A set of upper

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and lower punches in a rectangular cross-section with dimensions of width of 10mm and length of 25mm and various thickness were used. A die of same dimensions was used to manufacture all 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 cross-head movement rate of 1 mm/minute. The same compaction pressure were used to compact the upper and lower layers of the composite tablets. As the rectangular specimen was subjected to test apparatus, its tensile strength was calculated from the load at fracture (figure 2). The tablet was supported at two fixed points and an increasing load was applied on the centre of the tablet until it fractures.

For different material composite tablets, the strength calculation were carried out by using equation 1 for tensile stresses, equation 2 for compressive stresses, and equation 3 for shear stresses:

$$\sigma_f = Fhd\,(1+3n)/16(1+n)I \quad (1)$$

$$\sigma_c = Fhd\,(3+n)/16(1+n)I \quad (2)$$

$$\tau = Fd^2/64I\,(3+n/1+n)^2 \quad (3)$$

where F is applied loading in bending test, h is distance from support to support in three-point bending test, d and n are depth or thickness of a beam and number of components of composite beam, respectively and I is second moment of area of beam cross-section which is calculated by the following equation:

$$I = bd^3\,[(1+n/96) + (n^2+1/8(1+n)^2)] \quad (4)$$

All tablets after manufacturing were stored in sealed containers for 7 days at room temperature. Then they were individually subjected to three-point flexural bending test in a way that the force was applied to the middle top surface of the tablet by means of a CT-40 tablet tester 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 are based on 10 determinations for a given pressure of compaction.

The porosity which relates the bulk density of powders to their packing fraction (6), was determined for the same-material double-layer tablets (7).

RESULTS AND DISCUSSION

Tables 2(a and b) show that the extent of interaction between surfaces upon applied forces depend on the compaction pressure employed for manufacturing the Starch 1500/Emcompress tablets. Thus, for the high compaction pressure (80 Mpa) forces between surfaces were poor, and the tablet was split into its individual ingredients. With tablets made up of two different materials in the top and bottom layers, it was expected that their behaviour would be different depending on the side subjected to the bending force. However it was found that regardless of the material at the top or bottom part of the composite tablet, the bending force when the double-compacted material was located at the bottom side was higher than when it was located at the top side of the tablet. The theory of bending in composite beams was used to interpret this finding. The tensile stress at the lower surface of the beam was obtained at the time of fracture, as illustrated in tables 2-4.

In spite of anticipation, the value of σ_f for double layer beam of Emcompress-Starch when the Emcompress was loaded on top layer (table 2a), was more than the tensile strength of double-packed Starch 1500 (7) which was probably due to test errors. On the other hand, the value of σ_f was slightly more than the tensile strength of a single Emcompress tablet, when the Starch was loaded on the top (table 2b). This small difference might be due to the effect of the stronger double-packed Starch 1500 at the upper layer of the tablet which may result in delay of the fracture.

For the double-layer tablets composed of Starch on the upper layer and Avicel PH102 loaded in lower layer, the tensile stress at the lower surface of the tablet which is composed of material (Table 3a), was approximately equal to tensile strength of the twice-compacted Avicel PH102 obtained from the same material composite tablet (7). The value of σ_c (compressive stress on the upper surface) was much more than the tensile strength of a single compacted Starch 1500 tablet. However, as previously mentioned, this value can not play an important role since it is a compressive stress and is not able to propagate the cracks. Thus, the tablets did not fail until the σ_f exceeds the tensile strength of the material at its lower surface.

Meanwhile, when the Avicel was loaded on the top of double layer beam composed of Avicel and Starch, (table 3b), the calculated value of σ_f (maximum tensile stress on the lowest point of Starch 1500 layer) showed a higher tensile strength than for Starch 1500, as its value was more than that obtained from single tablet tests. A probable reason was that the upper layer composed of Avicel PH102, was much stronger than the lower layer, which in turn may cause some delays in fracturing of the tablet. As shown in tables, the fracture load and tensile strength values were higher when the Avicel PH102 material was set on the bottom surfaces of double layer beams.

In the case of double layer beam of Emcompress/ Avicel, when Emcompress was loaded on the upper layer, the values of σ_f at fracture (table 4a) were almost

Table 1. Modulus of elasticity of materials used.

Material	Size fraction (μm)	(E): Modulus of elasticity (Gpa)	References no.
Avicel PH102	90	8.67	2
Avicel PH102	250	4.70	9
Emcompress		7.00	8
Starch 1500		3.10	8

The young's modulus of Emcompress, Starch 1500 and Avicel PH102 (90μm) have been obtained from tensile stress, while for Avicel PH102 (250μm) it has been determined from compressive stress values.

Table 2a) Mechanical strength as a function of compaction pressure for double-layer beams of "Emcompress+Starch 1500".

Compaction Pressure (Mpa)	Material (T:Top) (B:Bottom)	Tickness d(cm)	Fracture Load (kgf)	Porosity	Compressive Stress σ_c(MNm^{-2} *0.1)	Tensile Stress σ_t(MNm^{-2} *0.1)	Shearing Stress τ (MNm^{-2} *0.1)
18	T:Emcomp. B:Starch	0.405	0.298	0.357	2.739	4.623	0.247
30	T:Emcomp. B:Starch	0.373	0.567	0.313	5.970	10.078	0.511
43	T:Emcomp. B:Starch	0.354	0.828	0.277	9.632	16.258	0.786
58	T:Emcomp. B:Starch	0.337	1.054	0.238	13.595	22.948	1.051
80	T:Emcomp. B:Starch	Twice-Shelled Tablets					

Table 2b) Mechanical strength as a function of compaction pressure for double-layer beams of "Starch 1500+ Emcompress".

18	T:Starch B:Emcomp.	0.405	0.120	0.357	3.716	2.269	0.497
30	T:Starch B:Emcomp.	0.373	0.249	0.313	9.032	5.514	1.120
43	T:Starch B:Emcomp.	0.354	0.403	0.277	16.230	9.09	1.910
58	T:Starch B:Emcomp.	0.337	0.413	0.238	18.413	11.241	2.056
80	T:Starch B:Emcomp.	Twice-Shelled Tablets					

Table 3a. Mechanical strength of double-layer beams of " Starch 1500+Avicel PH102".

Compaction Pressure (Mpa)	Material (T:Top) (B:Bottom)	Tickness d(cm)	Fracture Load (kgf)	Porosity	Compressive Stress σ_c(MNm^{-2} *0.1)	Tensile Stress σ_f(MNm^{-2} *0.1)	Shearing Stress τ (MNm^{-2} *0.1)
18	T:Starch B:Avicel	0.413	1.271	0.376	43.649	26.968	6.241
30	T:Starch B:Avicel	0.370	1.836	0.302	74.477	48.487	10.063
43	T:Starch B:Avicel	0.344	2.326	0.252	114.566	70.728	13.713
58	T:Starch B:Avicel	0.325	2.712	0.215	146.566	90.555	16.923
80	T:Starch B:Avicel	0.313	3.057	0.167	186.090	114.975	19.807

Table 3b. Mechanical strength of double-layer beams of "Avicel PH102+Starch 1500".

18	T:Avicel B:Starch	0.413	0.496	0.376	3.782	6.128	0.331
30	T:Avicel B:Starch	0.370	0.702	0.302	6.684	10.830	0.524
43	T:Avicel B:Starch	0.344	0.812	0.252	8.898	14.418	0.651
58	T:Avicel B:Starch	0.325	0.968	0.215	11.921	19.315	0.822
80	T:Avicel B:Starch	0.313	1.067	0.167	14.183	22.980	0.941

Table 4a. Mechanical strength as a function of compaction pressure for double-layer beams of "Emcompress+Avicel PH102".

Compaction Pressure (Mpa)	Material (T:Top) (B:Bottom)	Tickness d(cm)	Fracture Load (kgf)	Porosity	Compressive Stress σ_c(MNm^{-2} *0.1)	Tensile Stress σ_f(MNm^{-2} *0.1)	Shearing Stress τ (MNm^{-2} *0.1)
18	T:Emcomp. B:Avicel	0.426	1.113	0.391	19.512	16.369	2.419
30	T:Emcomp. B:Avicel	0.381	1.559	0.322	34.018	28.538	3.789
43	T:Emcomp. B:Avicel	0.354	2.011	0.269	50.837	42.648	5.260
58	T:Emcomp. B:Avicel	0.337	2.344	0.237	64.763	54.330	6.441
80	T:Emcomp. B:Avicel	0.326	2.770	0.207	82.749	72.419	7.868

Table 4b. Mechanical strength as a function of compaction pressure for double-layer beams of "Avicel PH102+ Emcompress".

18	T:Avicel B:Emcomp.	0.426	0.419	0.391	5.298	5.671	0.595
30	T:Avicel B:Emcomp.	0.381	0.616	0.322	9.733	10.419	0.978
43	T:Avicel B:Emcomp.	0.354	0.891	0.269	16.383	17.537	1.523
58	T:Avicel B:Emcomp.	0.337	1.034	0.237	20.935	22.410	1.856
80	T:Avicel B:Emcomp.	0.326	1.238	0.207	26.800	28.687	2.297

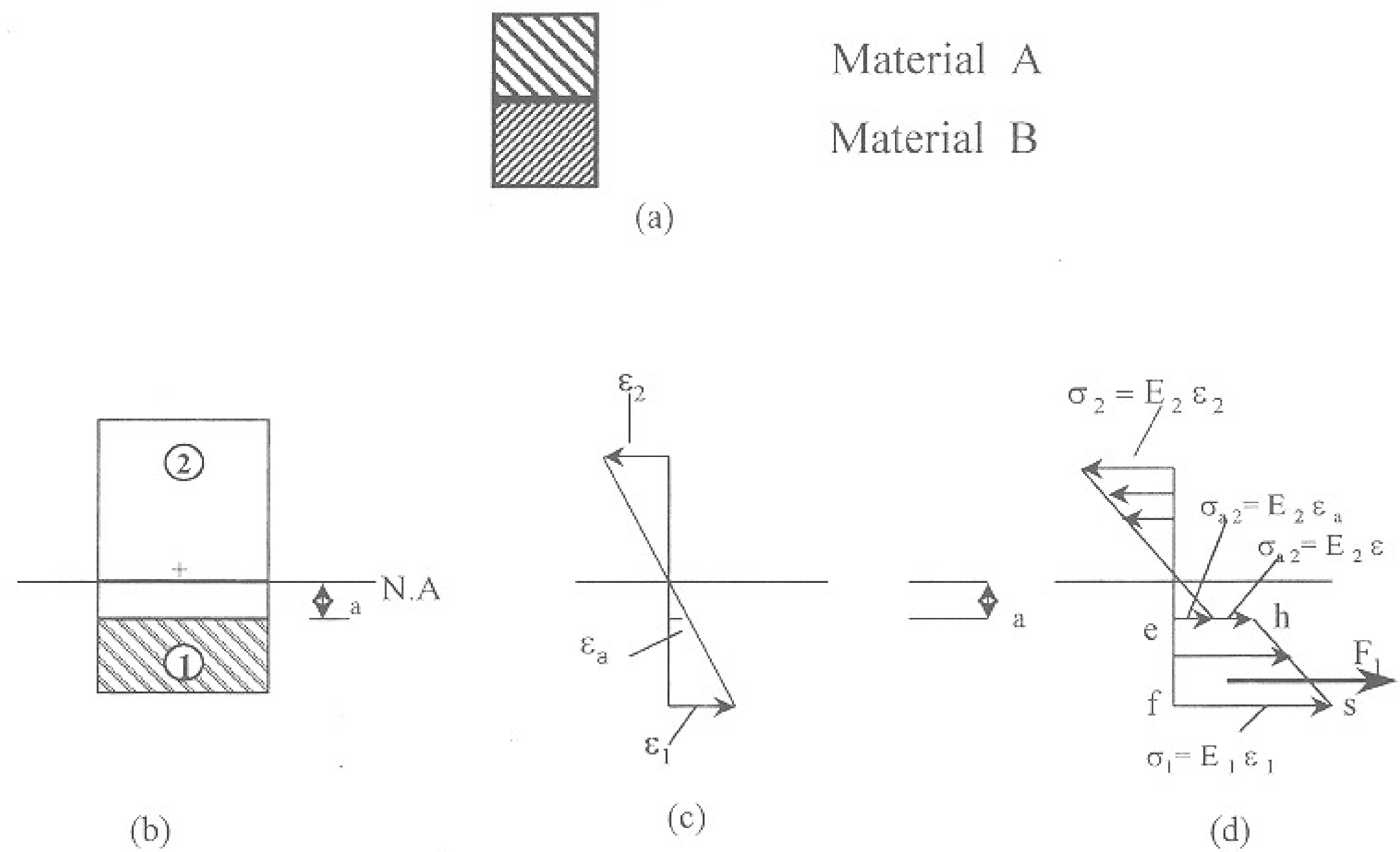

Figure 1.
a) Diagram of a composite beam, b) Neutral axis in a different material composite beam
c) The linear strain distribution, d) The stresses in a composite beam

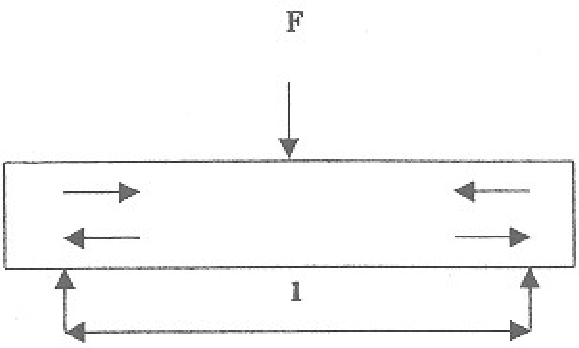

Figure 2. Beam loading to produce a bending

similar to the tensile strength of double-packed Avicel PH102 in the same material composite tablet (7). The tensile strength values were higher when the Avicel PH102 was set at the bottom surface. In contrast, the calculated value of σ_f (table 4b) was apparently much more than the tensile strength of the Emcompress obtained from single tablet tests when the Avicel was loaded on bottom layer. As anticipated, the existence of double-compacted Avicel PH102 may causes delay in the fracture of tablets. Hence, σ_f did not show the real strength of the Emcompress.

CONCLUSION

Comparison of the results obtained from the treatment of both surfaces of composite tablets showed that the behaviour of each material was different in compression than in tension, as the values of compressive stress (σ_c) and tensile stress (σ_f) obtained from both tests were different. It was also observed that the value of critical stresses in tension was higher than that in compression. Thus, when the strongest material was placed in the lower layer, the higher fracture load was exerted.

Composite tablets of Emcompress/Starch 1500 did not tolerate higher compaction pressures than 80 MPa, as they spliced down in two pieces by the axial plane between two surfaces. This was probably because of the existence of poor inter material Van der Waals forces, which in turn was due to the Emcompress characteristics. In the different material composite beams, if the material with higher modulus of elasticity was located at the top layer during testing, the tensile stress value of the specimen was higher than the compressive stress value, and vice versa.

When a high modulus material was located at top layer, it rather prevented the easy transmission of the force through the double-layer tablet. Thus, higher fracture load was needed to be applied in order to cause a failure at lower surface. In addition, higher modulus of elasticity caused the beam to bend easily.

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