

IJP 02297

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Effects of molecular coatings on the compression and tableting of some pharmaceutical powders

N. Pilpel, C.I. Igwilo * and S. Malamataris +

Chelsea Department of Pharmacy, King's College, University of London, Manresa Road, London SW3 6LX (U.K.)

(Received 31 August 1990)

(Accepted 22 September 1990)

Key words: Powder; Molecular coating; Compression; Tableting; Tensile strength; Plasto-elastic properties

Summary

Coating the particles of various pharmaceutical powders with up to 10 molecular layers of paraffins, fatty acids, surfactants, silicones and polymers noticeably alters their mechanical behaviour when they are compressed into beds or formed into tablets. At low packing fractions of 0.41 the tensile strengths of the beds tend to increase, then decrease and then increase again with increasing coating concentration. At higher packing fractions of 0.82 the tensile strengths of tablets generally decrease with coating concentration and there is an inverse relationship between their tensile strength and the ratio of the elasticity to the compression of the coated powders.

Introduction

Coating the particles in powders with molecular films of other substances noticeably alters their mechanical behaviour when they are compressed into beds or formed into tablets with a punch and die (Pilpel, 1986). The coatings, restricted in the present context to fewer than 10 molecules thick, constitute less than 3% of the total weight of the powder. Nevertheless, their effects are readily observed. For example, the pressure needed to consolidate powdered lactose approx. 20 μm in diam-

eter to a packing fraction ρ_F (= bulk density/particle density) of 0.4 decreased by a factor of 10 after the particles had been coated with three molecular layers, i.e. 1% w/w of stearic acid (Pilpel and Hepher, 1977).

The lubricating/glidant action of sorbed films of moisture (at higher concentrations water begins to act as an antilubricant, i.e. as a binding agent) (Cheng, 1970; Eaves and Jones, 1972) micro-fine silica (Aerosil) (Varthalis and Pilpel, 1977) and other substances on the surfaces of a variety of individual powders and formulated mixtures of powders has been investigated in the context of tableting technology (Lachman et al., 1970; Pilpel, 1971; Moody et al., 1981). However, only a small amount of this work precisely relates to molecular films (Irono and Pilpel, 1982; Malamataris and Pilpel, 1982; Sakr and Pilpel, 1982) either because the coatings were obviously thicker than the 10 molecules presently stipulated or because their

Correspondence: N. Pilpel, Chelsea Dept. of Pharmacy, King's College, University of London, Manresa Rd, London SW3 6LX, U.K.

* *Present address:* School of Pharmacy, College of Medicine, University of Lagos, Lagos, Nigeria.

+ *Present address:* Department of Pharmacy, University of Thessaloniki, Thessaloniki, Greece.

thickness was uncertain because the powder had not been adequately defined in regard to particle size and specific surface area.

If one excludes data on the effects of molecular coatings of water on the properties of powders — a subject which has been extensively studied (Eaves and Jones, 1972; Coelho and Harnby, 1978a,b; Chan, 1982; Zografi et al., 1983, 1984; Khan, 1987; Malamataris and Dimitriou, 1990) — there seems to be little information available on the effects produced by molecular coatings, in contrast to general additions of other materials.

The purpose of this paper has been to obtain new experimental data and to combine it with what is already available to show how molecular films of a variety of paraffins, fatty acids, surfactants, silicones, and polymers affect the compressional properties of representative pharmaceutical powders and the strengths of their compressed beds and tablets.

Experimental

Materials

The powders used were pharmaceutical grades of lactose, sodium chloride (B.P. Evans Medical), calcium phosphate dihydrate (Emcompress Forum Chemicals), calcium carbonate (Sturge Chemicals), and sodium salicylate (Macarthy's, Romford). They were chosen because they are known to be insoluble in and unaffected chemically by the materials selected to coat them and because they have different compressional properties (Malamataris and Pilpel, 1983; Wong et al., 1988).

Emcompress tends to fragment, sodium chloride tends to deform; lactose and sodium salicylate are easily compressible while calcium carbonate can only be compressed with difficulty.

The powders were sieved, dried under vacuum at 105°C and the material smaller than 33 μm was passed through a Microplex zig-zag classifier (Alpine, Augsburg) to obtain the fraction between 0 and 20 μm in diameter. Mean projected particle diameters d (μm) were determined by optical microscopy, specific surface areas S ($\text{m}^2 \text{g}^{-1}$) by nitrogen adsorption using a Perkin Elmer Sorptometer (Model 212C) and particle densities ρ_p with a Beckman air comparison pycnometer Model 930. Relevant properties of the powders are tabulated in Table 1.

Preparation of samples

The powders were coated with between 10^{-8} and 10^{-4} mol g^{-1} , i.e. up to a maximum of 3% w/w of the following materials, all of which find uses as excipients in pharmaceutical formulations: liquid paraffin, white soft paraffin, paraffin wax (B.P. grades from Evans Medical); hexadecanoic (palmitic), octadecanoic (stearic) acids ($\sim 99\%$ pure from Ralph N. Emmanuel); silicones DC 200/20 and DC 200/50 (Hopkins and Williams); sorbitan monostearate (Span 60), sorbitan monooleate (Span 80) (A.R. grades, Fisons); polysorbates Tween 40 and Tween 60 (Hopkins and Williams); polyethylene glycol (PEG mol. wt. 20000, Hoechst AG, Frankfurt); and polyvinyl pyrrolidone (PVP mol. wt. 40000, Aniline Films Co.). Relevant physicochemical properties of these materials are given in Table 2.

TABLE 1
Properties of powders

Powder	Mol. wt.	Moisture (% w/w)	Particle density (g cm^{-3})	Average particle diameter (μm)	Specific surface area ($\text{m}^2 \text{g}^{-1}$)
Lactose	360	< 0.5	1.55	12	2.7
Sodium chloride	58.4	< 0.2	2.15	11	2.5
Calcium phosphate (Emcompress)	136	< 0.5	2.30	14	2.9
Calcium carbonate	100	< 0.2	2.69	11	2.2
Sodium salicylate	160	< 0.5	1.67	12	1.8

TABLE 2

Properties of coatings

Coating	Physical nature	Mean solidifying/ melting point (°C)	Mean mol. wt.	Density (g cm ⁻³)
Liquid paraffin	liquid	4 to 5	226	0.88
White soft paraffin	semisolid	47 to 49	304	0.84
Paraffin wax	solid	52	335	0.90
Hexadecanoic acid	solid	59	256	0.92
Octadecanoic acid	solid	70	285	0.94
Silicone DC 200/20	liquid	-60	750	0.96
Silicone DC 200/50	liquid	-50	3450	0.97
Span 60	solid	-	431	0.99
Span 80	liquid	-	429	0.99
Tween 40	semisolid	35	1284	1.09
Tween 60	semisolid	40	1312	1.09
PEG 20 000	solid	58	20 000	1.19
PVP 40 000	solid	236	40 000	1.10

250 g of powder was mixed with 0.4 l of an aqueous or ethereal solution/dispersion containing the required amount of coating material and the solvent was recovered by distillation with continuous stirring. The powders were stored for several days in vacuo over silica gel to remove all traces of solvent and were tumbled to distribute the coatings. They were then deaggregated by passing through a 33 μ m stainless-steel sieve (other metals would be corroded by the fatty acids).

The thickness of the coatings of the fatty acids and surfactants, which are assumed to be vertically orientated, were calculated from a knowledge of Avogadro's number, the cross-sectional area of the coating molecule, the weight of coating per g of powder and the latter's specific surface area S (m² g⁻¹) (Irono and Pilpel, 1982; Sakr and Pilpel, 1982). The paraffins, silicones and polymers were assumed to be lying flat and the thickness of the coating was obtained directly from their density, the weight of coating (g⁻¹) of powder and its specific surface area. To calculate the number of molecular layers in these cases it was assumed that each was approx. 1 nm thick.

Testing

The tensile strengths of the powders were measured in triplicate at packing fractions up to 0.5 in a standard split-plate tensile tester (Ashton et al., 1964; Irono and Pilpel, 1982) which had been electroplated inside with a nickel-tin alloy (Atlas Electroplating Ltd) to prevent it being corroded by the fatty acids. Friction between the moveable half-cell and the base was minimised by fitting it with a glass plate and the apparatus was operated manually to reduce vibration. At the same time a record was kept of the pressure P that had been employed to achieve each packing fraction.

Replicate samples of 300–400 mg were compressed into 10.5 mm diameter flat-faced tablets in a Dartec universal testing machine (Dartec Ltd) applying a maximum load of 20 kN for a period of 10 s to achieve ρ_F values between 0.80 and 0.90 (the usual range for commercial tablets), held at this load for 30 s and then decompressed over a further 30 s [the reasons for choosing these conditions and full experimental details have been published elsewhere (Bangudu and Pilpel, 1985)].

If H_p and H_t are, respectively, the thicknesses

of the tablet at maximum load and after holding for 30 s and H_0 is the final thickness of the tablet after removing from the die and storing it in a desiccator for 24 h to recover elastically, then the compression

$$C = \frac{H_p - H_t}{H_t} \times 100\% \quad (1)$$

and the elastic recovery

$$ER = \frac{H_0 - H_t}{H_t} \times 100\% \quad (2)$$

It has been shown (Bangudu and Pilpel, 1985) that the ratio ER/C can be used to provide a comparative measure of the changes that occur in the plastoelastic properties of powders as the nature and thickness of the coatings that have been applied to the particles are altered.

The finished tablets were fitted with cardboard padding strips to distribute the load and were

placed on edge on the base of the Dartec. Load was applied with the upper punch at the rate of 1 mm min^{-1} until they broke cleanly in half along a diameter. The tensile strength T was calculated from the expression (Fell and Newton, 1970)

$$T = \frac{2L}{\pi D H_0} \quad (3)$$

where L is the load causing failure and D is the diameter of the tablet. Measurements were carried out in triplicate and only results from clean diametral breaks were accepted.

Results and Discussion

The results showed that within the usual range of scatter (Ashton et al., 1964; Pilpel and Hephner, 1977; Sakr and Pilpel, 1982) the tensile strengths of all the samples increased logarithmically with increasing ρ_F up to 0.5 and that straight lines with correlation coefficients greater than 0.96 for at

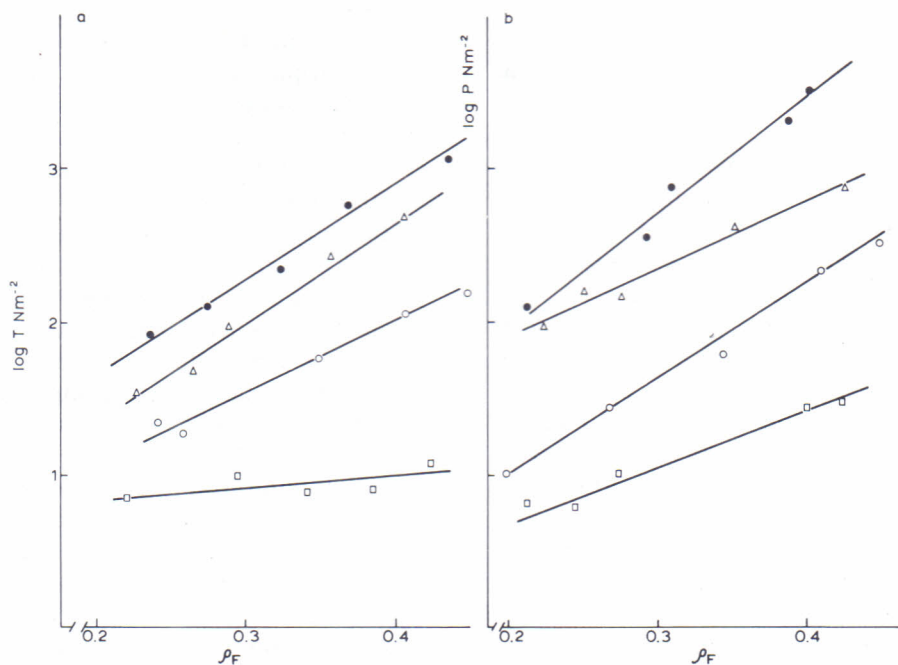


Fig. 1. (a) Log tensile strength T (N m^{-2}) vs packing fraction ρ_F for powders. (b) Log compression force P (N m^{-2}) vs packing fraction ρ_F for powders. (○) Lactose; (□) lactose + $2 \times 10^{-5} \text{ mol g}^{-1}$ stearic acid; (△) lactose + $5 \times 10^{-5} \text{ mol g}^{-1}$ stearic acid; (●) lactose + $10 \times 10^{-5} \text{ mol g}^{-1}$ stearic acid.

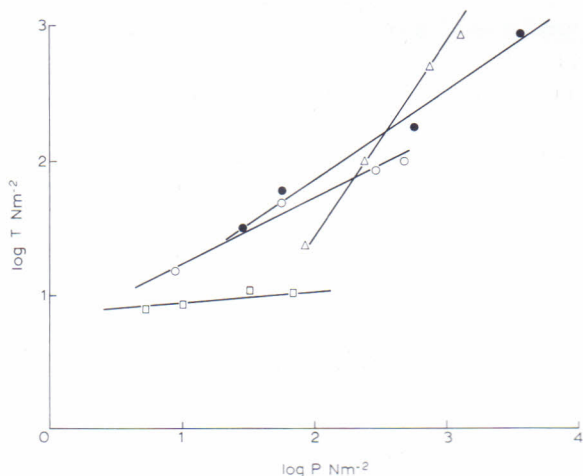


Fig. 2. Log tensile strength T (N m^{-2}) vs log compression force P (N m^{-2}) for powders. Symbols as in Fig. 1.

least seven points could be fitted through them by regression analysis

$$\log T = A\rho_F + B \quad (4)$$

There were also logarithmic relationships between the pressure P applied to each sample and the packing fraction achieved, i.e.

$$\log P = A_1\rho_F + B_1 \quad (5)$$

where A , A_1 , B and B_1 are constants which depend on the nature of the powder and on the nature and amount of coating material employed. Typical graphs to illustrate these relationships are plotted in Fig. 1a and b*.

It follows that there should also be relationships between P and T , i.e.

$$\log T = A_2 \log P + B_2 \quad (6)$$

where A_2 and B_2 are further constants. This was confirmed in several cases: the results from Fig. 1 are plotted in Fig. 2*. One can compare the effects of the different coatings on the tensile strengths of the different powders by arbitrarily

selecting a ρ_F of 0.41 (to avoid the need to extrapolate the graphs in Fig. 1) and plot $\log T$ at ρ_F 0.41 vs the molar concentrations of the coatings. It was found that the results depended both on the nature of the substrate and on the coating employed.

Fig. 3a shows that for lactose coated with fatty acids, the lower molecular weight paraffins or with the surfactants T initially increased, then decreased as the coating concentration was increased up to about $2-4 \times 10^{-5} \text{ mol g}^{-1}$ and then increased again. Detailed calculations (Pilpel and Hephher, 1977; Irono and Pilpel, 1982; Sakr and Pilpel, 1982) show that the minima correspond to films between two and five molecules thick, depending on their molecular weight. The pattern produced for lactose coated with palmitic acid and with Span 80 was similar and similar results have also been reported when small amounts of water are added to powders (see review by Khan (1987)). However, on the substrates of sodium chloride and Emcompress and with paraffin wax, PEG or PVP on all three substrates, different results were obtained, the tensile strengths either increasing steadily or increasing and then decreasing (see Fig. 3b and c) with coating concentration.

At higher concentrations, namely above 3% w/w (i.e. outside the range of the present investigation), the graphs could again change direction which would account for apparent contradictions in the literature on the effects produced by additives on the tensile strengths of powders (Kurup, 1979).

In several cases, the graphs of P vs coating concentration were of the same general shape as those of T vs concentration (cf., for example, Fig. 3a and b with Fig. 4). The value of P which is essentially the resistance of a powder to compression and that of T are both ultimately determined by the range and magnitude of the physical, van der Waals', and mechanical frictional forces that act between the particles (Malamataris and Pilpel, 1982). In the present systems, these will depend on the plasticity, elasticity, mechanical strength, uniformity and durability of the coatings. Friction between surfaces arises from the elastic and plastic deformation that takes place at the true points of contact between neighbouring asperities and it

* To avoid confusion only a few of the experimental points are plotted but there were enough for regression analysis to be carried out.

seems likely that the same mechanisms are responsible for the present changes in T and P as the nature and thickness of the coatings covering these asperities are altered. Addition of a plastic coating such as paraffin wax or PEG causes a

greater area of real contact to develop between the particles. This produces an increase in the cohesion between them and accounts for the rises in the curves in Fig. 3b and c. Addition of a more elastic coating such as PVP produced the opposite

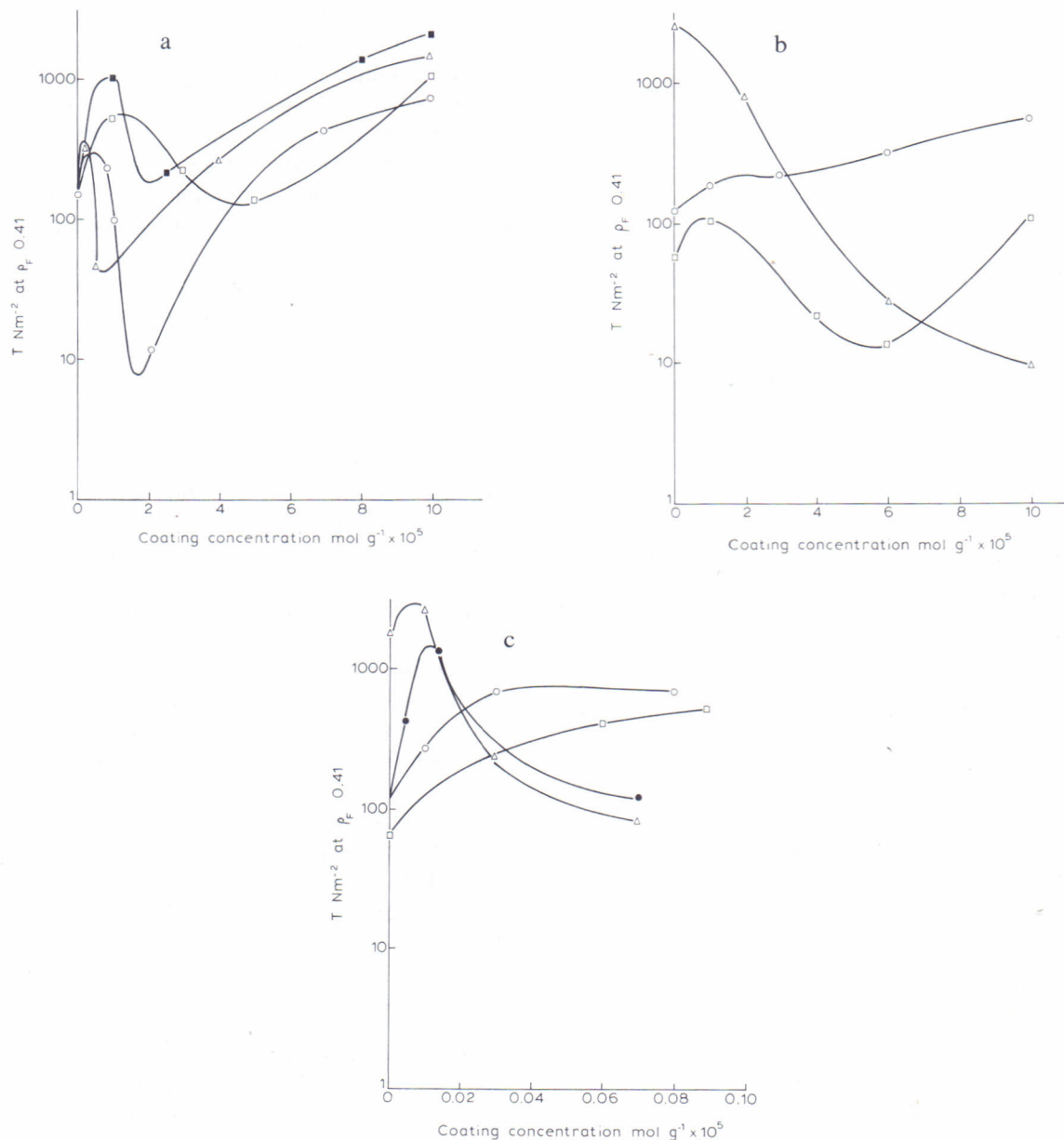


Fig. 3. Log tensile strength T (N m⁻²) at ρ_F 0.41 vs coating concentration (mol g⁻¹ × 10⁵) for powders. (○) Lactose + stearic acid; (□) lactose + liquid paraffin; (Δ) lactose + Span 60; (■) lactose + white soft paraffin. (b) (○) Lactose + paraffin wax; (□) Emcompress + palmitic acid; (Δ) sodium chloride + stearic acid. (c) (○) Lactose + PEG; (●) lactose + PVP; (Δ) sodium chloride + PVP; (□) Emcompress + PEG.

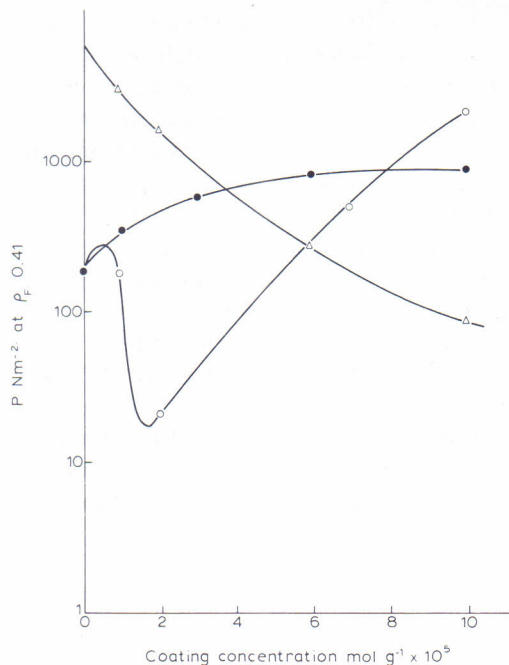


Fig. 4. Log compression force P (N m^{-2}) at ρ_F 0.41 vs coating concentration ($\text{mol g}^{-1} \times 10^5$) for powders. (○) lactose + stearic acid; (●) lactose + paraffin wax; (Δ) sodium chloride + stearic acid.

effect of a decrease in tensile strength and resistance to compression (Fig. 3c). When a fatty acid, a low molecular weight paraffin or a surfactant is coated on lactose, sodium chloride or calcium phosphate (Emcompress), the initial decreases in both T and P can be ascribed to the coatings initially acting as lubricants (Pilpel and Hephher, 1977; Irono and Pilpel, 1982). However, the indications are that at concentrations greater than $10 \times 10^{-5} \text{ mol g}^{-1}$ (say about 10 molecules thick) these additives begin to act instead as binding agents causing the graphs to rise.

At various times attempts have been made to explain these results in terms of the formation of continuous or discontinuous coatings, absorption of material into particle pores (Pilpel and Hephher, 1977); softening and deformation of surfaces, e.g. by the phenomenon of asperitic melting under pressure (Carstensen, 1980), the formation of pendular bonds at higher coating concentrations (Cheng, 1970), etc. The combined action of all

these mechanisms could account for the diverse shapes of the graphs now obtained.

Tablets

We turn now to the results of the tableting tests in which the tensile strengths of the tablets were measured by diametral compression as described earlier.

Again there were found to be rectilinear relationships between $\log T$ and ρ_F for both the uncoated and coated powders and typical results are plotted in Fig. 5 (see footnote, p. 161). Selecting this time a ρ_F of 0.82, which is appropriate to tablets, graphs were plotted between $\log T$ at ρ_F 0.82 and the concentration of coating. Typical results in Fig. 6a and b show that up to concentrations of 10×10^{-5} and $5 \times 10^{-5} \text{ mol g}^{-1}$, respec-

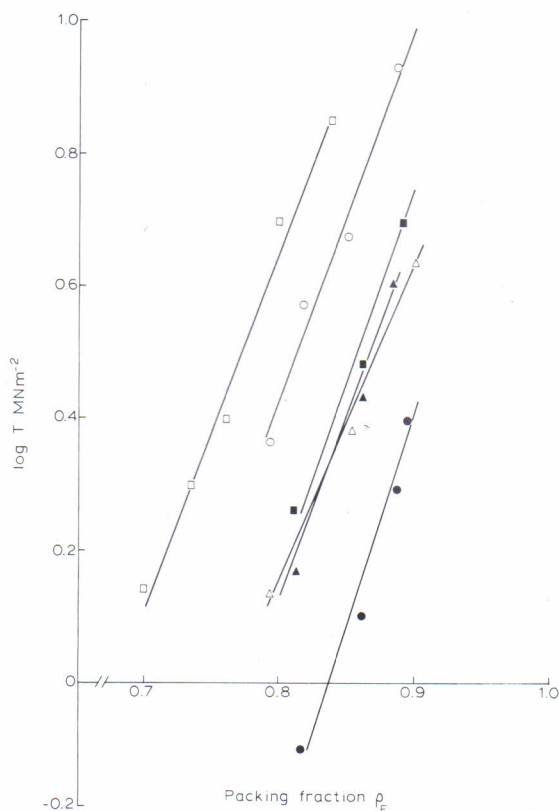


Fig. 5. Log tensile strength T (MN m^{-2}) vs packing fraction ρ_F for tablets. (○) Lactose; (●) lactose + $10^{-4} \text{ mol g}^{-1}$ stearic acid; (Δ) sodium chloride; (▲) sodium chloride + $5 \times 10^{-7} \text{ mol g}^{-1}$ PVP; (□) Emcompress; (■) Emcompress + $5 \times 10^{-5} \text{ mol g}^{-1}$ white soft paraffin.

tively, the fatty acids, paraffins, silicones and surfactants caused large decreases in the tensile strengths of all the tableted powders. This accounts for their long-established use as lubricants in tableting technology. The effects of paraffin wax, PEG and PVP were rather different (see, for example, Fig. 6c).

It was thought of interest to see whether these effects were reflected in changes in the plastoelastic properties of the powders as measured by their compressibility C and their elastic recovery ER . C is the sum of the plastic, elastic and viscoelastic deformation of a powder under particular compressional conditions (Bangudu and Pilpel, 1985) and ER is its subsequent elastic recovery when the load is removed. The ratio ER/C is not an

absolute quantity, since no allowance is made during its measurement for deformation or recovery of the powder in a radial direction. Nevertheless, it seemed reasonable to expect that the ratio should provide some comparative measure of the changes produced by the coatings in the tableting characteristics of the powders.

Comparing Figs 6a, b and 7 it is seen that the coatings generally produced decreases in the tensile strengths of the tablets (some exceptions are shown in Fig. 6c), but increases in their values of ER/C and vice versa. The inverse relationship between T (more precisely $\log T$) and ER/C has been noted previously (Bangudu and Pilpel, 1985) for a variety of other powders, both with and without coatings, showing that T , ER/C and P are all interrelated

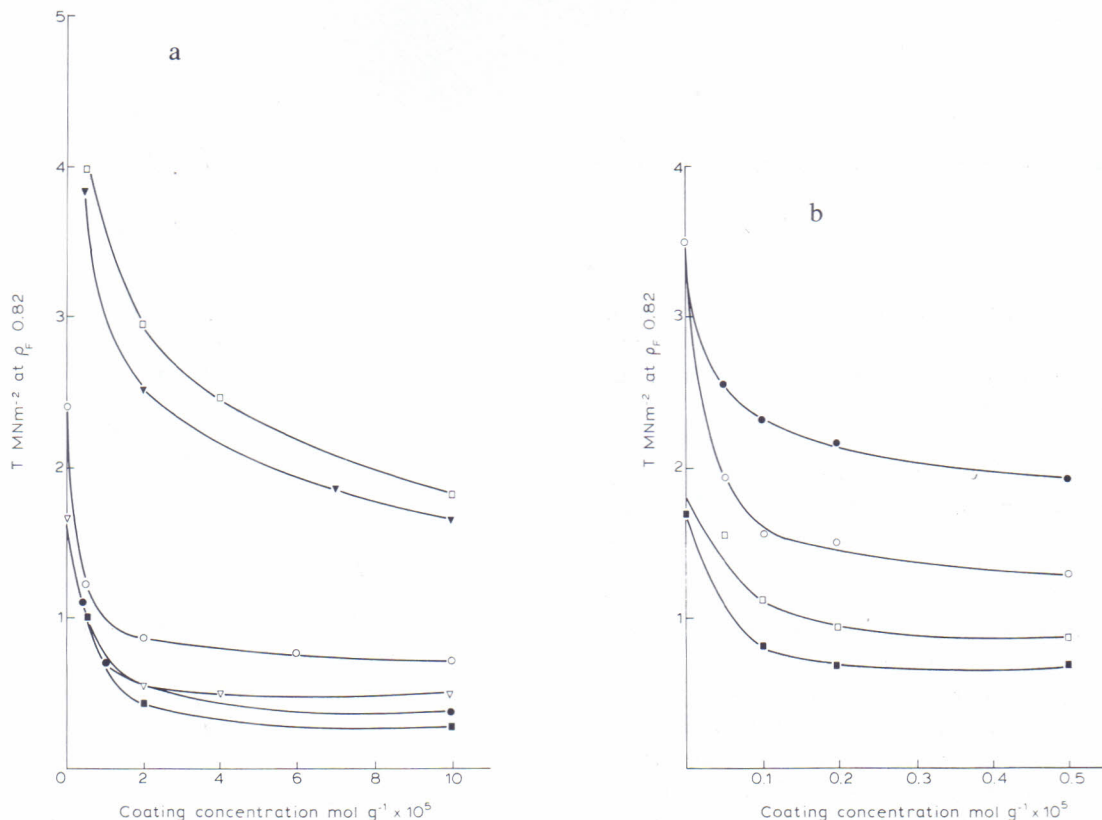


Fig. 6. Tensile strength T (MN m^{-2}) at $\rho_F 0.82$ vs coating concentration ($\text{mol g}^{-1} \times 10^5$) for tablets. (a) (\circ) Lactose + stearic acid; (\bullet) lactose + liquid paraffin; (\blacksquare) lactose + Span 60; (∇) sodium chloride + stearic acid; (\square) Emcompress + stearic acid; (\blacktriangledown) Emcompress + white soft paraffin. (b) (\circ) Sodium salicylate + silicone 200/50; (\bullet) sodium salicylate + Tween 40; (\square) calcium carbonate + silicone 200/20; (\blacksquare) calcium carbonate + Tween 60. (c) (\circ) Lactose + PEG; (\bullet) lactose + PVP; (∇) sodium chloride + PEG; (\blacktriangledown) sodium chloride + PVP; (\square) Emcompress + PEG; (\blacksquare) Emcompress + PVP.

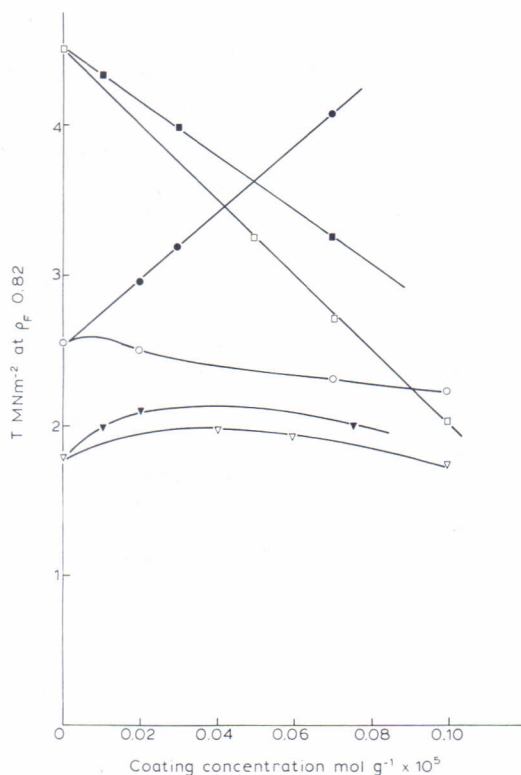


Fig. 6 (continued).

measures of the compressional and tableting properties of powders.

Conclusion

It is concluded from this investigation that these properties are markedly altered by the presence on the particles of molecular coatings of other materials, the effects depending both on the nature and on the precise thickness of the coatings, up to about 10 molecules. Other properties of tablets which will be affected by coating the particles will be their wettability and rate of dissolution (Pilpel, 1971; Moody et al., 1981; Igwilo and Pilpel, 1983). The paraffins, fatty acids and silicones, being hydrophobic, cause reductions in the rate of dissolution; the surfactants, being hydrophilic, cause increases.

It will be important to ensure that these effects are also considered if coatings are to be applied to

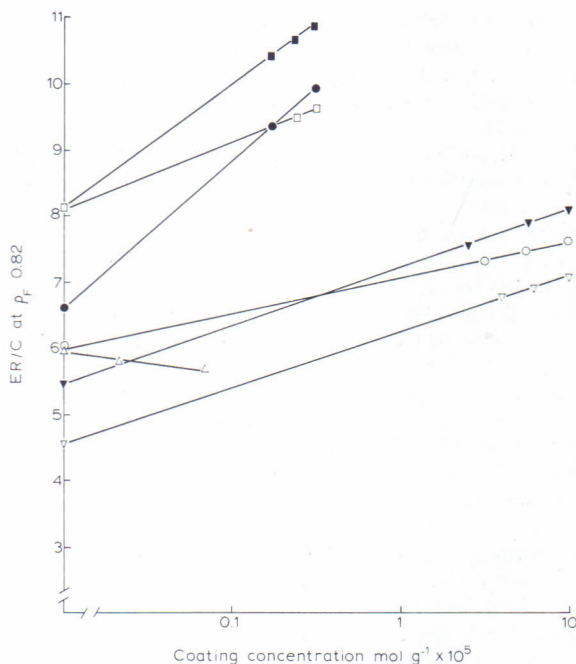


Fig. 7. ER/C at ρ_F 0.82 vs coating concentration ($\text{mol g}^{-1} \times 10^5$) for tablets. (○) Lactose + stearic acid; (△) lactose + PVP; (▽) sodium chloride + palmitic acid; (▼) Emcompress + white soft paraffin; (●) sodium salicylate + silicone 200/50; (□) calcium carbonate + silicone 200/20; (■) calcium carbonate + Tween 60.

powders to be used in the preparation of pharmaceutical tablets.

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