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Relation between crushing strength and internal specific surface area of lactose compacts

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Summary

The theoretical considerations presented here explain the experimentally known proportionality between the crushing strength and internal specific surface area of lactose compacts. The theoretical model permits the calculation of coordination numbers of spherical isometric particles, which form a compact held together by dispersion forces. The mean particle size was calculated on the basis of the internal specific surface area. The results depend on the experimental method used, i.e. mercury intrusion porosimetry, BET-nitrogen adsorption or gas permeametry.

Introduction

One of the most striking results in Vromans' thesis (1987) is the experimentally found relationship between the crushing strength of different types of lactose tablets (anhydrous α-lactose, α-lactose monohydrate, roller-dried β-lactose) and the internal specific surface area. Vromans et al. (1985) and Vromans (1987) assume that the number of binding sites is proportional to the specific surface area determined. This proportionality is shown to be valid using a theoretical approach to calculate the tensile strength of the tablet on the basis of Van der Waals' dispersion forces.

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Theory

The potential energy per unit area E resulting from dispersion forces acting between two perfectly flat surfaces in contact is given by Fowkes (1971) and Hiestand (1985):

$$E = \frac{A}{12\pi z_0^2} \tag{1}$$

Where A is the Hamaker constant and z_0 is the closest approach distance of the surface molecules. This should be equal to the loss of specific surface energy $2\gamma^d$, resulting from dispersion forces (superscript d), when the surfaces are brought together. Thus the Hamaker constant A can be calculated as follows:

$$A = 24\pi z_0^2 \gamma^d \tag{2}$$

Rumpf (1970) developed, based on statistical considerations, a general equation for the tensile strength of an agglomerate, where the strength is caused by adhesion forces F acting at the coordination points of the particles forming the agglomerate. Assuming that the particles which form

TABLE 1

Experimental results for different types of lactose and different particle size fractions of α-lactose monohydrate.

Type of lactose	Compaction pressure (MPa)	Porosity (Hg) (%)	Crushing strength (N)	Surface area S_m (m^2/g)	Tablet thickness (mm)
α-Lactose monohydrate (32–45 μm)	55	24.5	16.7	0.62	3.237
	150	13.5	72.6	1.24	2.845
	225	11.1	98.1	1.59	2.729
α-Lactose monohydrate (100–125 μm)	75	16.8	20.6	0.49	3.001
	112.5	15.6	33.4	0.79	2.920
	150	12.2	42.2	0.83	2.770
	225	10.0	62.8	1.26	2.710
	300	7.4	83.4	1.51	–
α-Lactose monohydrate (125–160 μm)	55	18.6	10.8	0.46	3.021
	112.5	14.9	39.2	0.81	2.855
	150	12.4	51.0	0.88	2.778
	185	11.1	61.8	0.98	2.760
	225	9.7	71.6	1.14	2.710
α-Lactose monohydrate (315–400 μm)	55	16.4	9.8	0.34	2.933
	112.5	13.6	22.6	0.60	2.840
	150	11.6	37.3	0.65	2.751
	185	10.2	48.1	0.81	2.712
	225	9.3	55.9	0.96	2.680
Anhydrous α-lactose (100–125 μm)	37.5	20.7	34.3	0.79	3.185
	75	18.5	72.6	1.24	2.933
	112.5	15.3	110.9	1.64	2.865
	150	12.3	147.2	2.12	2.754
	225	9.5	~ 216	3.14	2.641
Roller-dried β-lactose (100–125 μm)	37.5	25.8	24.5	0.53	3.312
	75	21.2	52.0	0.86	3.019
	112.5	16.4	69.7	1.21	2.873
	150	13.2	104.0	1.46	2.765
100% Amorphous spray-dried lactose	37.5	22.6	~ 10	0.53	–
	55	21.3	67.7	0.64	–
	75	19.1	106.9	0.66	–
	95	18.9	169.7	0.55	–
	115	12.5	~ 196	0.61	–
	150	8.3	> 200	0.56	–
	225	4.3	≫ 200	0.54	–
DC lactose 11 "spray-dried lactose"	37.5	29.5	37.3	0.55	–
	75	20.4	73.6	0.58	–
	112.5	17.0	110.9	0.87	–
	150	13.9	147.2	1.10	–
	225	10.1	~ 220	1.50	–

The specific surface area was determined by mercury intrusion porosimetry.

the agglomerate are of uniform size (particle diameter = x), that $\bar{k}$ is the average coordination number and ϵ is the porosity of the agglomerate, tensile strength σ_t can be approximated as follows:

$$\sigma_t = \frac{1-\epsilon}{\pi}\bar{k}\frac{F}{x^2} \tag{3}$$

The adhesion force F is always proportional to the particle diameter x and inversely proportional to the squared minimum distance z_0^2. For the model sphere/plane (spherical particle with diameter x) the adhesion force F^* is equal to

$$F^* = \frac{Ax}{12z_0^2} \tag{4a}$$

Thus force F^* is exerted on an isolated particle attached to the plate, i.e. plate one. The next neighbouring particle (with equal diameter) is a part of plate one. If this particle is isolated and attached to a second plate the identical force F^* will act. The superposition of these forces yields

$$F = \frac{Ax}{6z_0^2} \tag{4b}$$

If Eqns. 3, 4b and 2 are combined, the following

TABLE 2

Specific surface values S_m determined by nitrogen gas adsorption for different types of lactose compacts compacted at 37.5 MPa

Type of lactose	Size fractions (μm)	Crushing strength (N)	Surface area S_m (m^2/g)
Anhydrous α-lactose	24–32	55.9	1.48
	32–63	48.1	1.15
	63–100	43.2	0.98
	100–160	40.2	0.91
	160–200	39.2	0.86
	250–315	32.4	0.72
α-Lactose monohydrate	24–32	18.6	0.70
	32–63	17.7	0.52
	63–100	11.8	0.48
	160–200	8.8	0.36
	250–315	7.8	0.34
Roller-dried β-lactose	32–63	32.4	0.83
	63–100	29.4	0.72
	100–160	23.5	0.61
	250–315	25.5	0.62
Crystalline β-lactose	32–63	15.7	0.57
	63–100	14.7	0.42
	160–200	9.8	0.35
	250–315	6.9	0.33

TABLE 3

Specific surface values S_m determined by gas permeametry for compacts of α-lactose monohydrate

Size fractions (μm)	Compaction pressure (MPa)	Crushing strength (N)	Surface area S_m (m^2/g)
24–32	50	24.0	0.29
	75	40.4	0.38
	100	52.4	0.53
	125	72.0	0.64
	150	98.6	0.83
32–63	50	–	0.21
	75	23.0	0.26
	100	40.8	0.34
	125	52.2	0.44
	150	62.4	0.65
63–100	50	10.5	0.15
	75	25.0	0.22
	100	35.4	0.29
	125	47.1	0.35
	150	56.9	0.43
100–160	50	8.7	0.13
	75	20.0	0.20
	100	27.1	0.22
	125	–	–
	150	45.5	0.39
160–200	50	–	0.10
	75	17.5	0.16
	100	23.4	0.21
	125	34.0	0.30
	150	40.6	0.36
200–250	50	12.0	0.09
	75	19.6	0.13
	100	27.8	0.22
	125	34.1	0.31
	150	42.6	0.32
250–315	50	11.5	0.07
	75	13.2	0.12
	100	18.4	0.18
	125	27.3	0.25
	150	32.0	0.35

TABLE 4

Specific surface values S_m determined by gas permeametry for compacts of crystalline β-lactose

Size fractions (μm)	Compaction pressure (MPa)	Crushing strength (N)	Surface area S_m (m^2/g)
32–63	75	34.4	0.31
	100	46.8	0.41
	125	58.6	0.74
	150	63.6	0.81
100–160	75	25.4	0.15
	100	36.8	0.24
	125	46.8	0.33
	150	57.2	0.45
160–200	75	16.4	0.12
	100	24.2	0.20
	125	–	–
	150	45.2	0.33
200–250	75	13.8	0.13
	100	24.0	0.17
	125	34.1	0.26
	150	44.0	0.30
250–315	75	18.6	0.14
	100	28.8	0.19
	125	38.8	0.28
	150	44.2	0.34

relationship for tensile strength σ_t is obtained:

$$\sigma_t = \bar{k}(1-\epsilon)\frac{4\gamma^d}{x} \tag{5}$$

In Eqn. 5 the coordination number $\bar{k}$, the critical specific surface energy γ^d and the diameter x of the particles forming the agglomerate (tablet) are unknown. It is possible to measure the internal specific surface area S_v. From this value a mean particle diameter $\bar{x}$ can be determined: by e.g. mercury intrusion porosimetry, BET gas adsorption or gas permeametry. The experimental results are compiled in Tables 1–4.

$$\bar{x} = \frac{6}{S_v} = \frac{6}{S_m \rho} \tag{6}$$

Thus inserting Eqn. 6 in Eqn. 5 the following relationship is obtained:

$$\sigma_t = \frac{2\bar{k}(1-\epsilon)}{3}\gamma^d S_m \rho = cS_m \tag{7}$$

This shows the proportionality between tensile strength and the internal specific surface area S_m of the agglomerate or tablet tested. The proportionality constant c is equal to

$$c = \frac{2\bar{k}(1-\epsilon)\gamma^d \rho}{3} \tag{8}$$

For the critical specific surface energy γ^d the following value was adopted from Lerk et al. (1976) as a rough estimate: γ^d (lactose) = 71.6 mJ/m^2.

Thus it is possible to calculate the coordination number $\bar{k}$ of our idealized isometric spherical particles with mean diameter $\bar{x}$, which are in contact with each other:

$$\bar{k} = \frac{3\sigma_t}{2(1-\epsilon)\gamma^d S_m \rho} \tag{9}$$

It is advantageous to take into account the equation for radial tensile strength

$$\sigma_t = \frac{2F_c}{\pi D d} \tag{10}$$

with F_c = crushing strength (N), D = diameter of the tablet, d = thickness of the tablet, and the following relations

$$\frac{d_\infty}{d} = 1-\epsilon \tag{11}$$

$$V = \frac{\pi D^2}{4} d_\infty = \frac{m}{\rho} \tag{12}$$

with d_∞ = tablet thickness for porosity $\epsilon = 0$, m = tablet mass, ρ = true specific density of the material compacted, V = volume of the tablet with thickness d_∞. Eqns. 10–12 can be applied to simplify Eqn. 9:

$$\bar{k} = \frac{3D}{4\gamma^d}\frac{F_c}{S_m m} \tag{13}$$

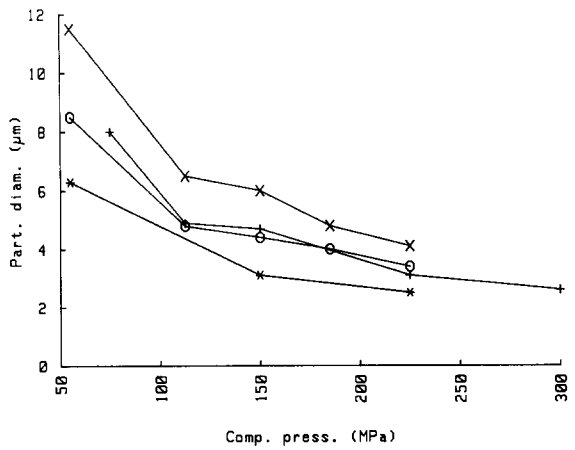

Fig. 1. Mean particle diameter $\bar{x}$ as a function of compaction pressure for compacts of α-lactose monohydrate with different initial particle size (see Table 7): (*), 32–45 μm; (+), 100–125 μm; (○), 125–160 μm, (×), 315–400 μm.

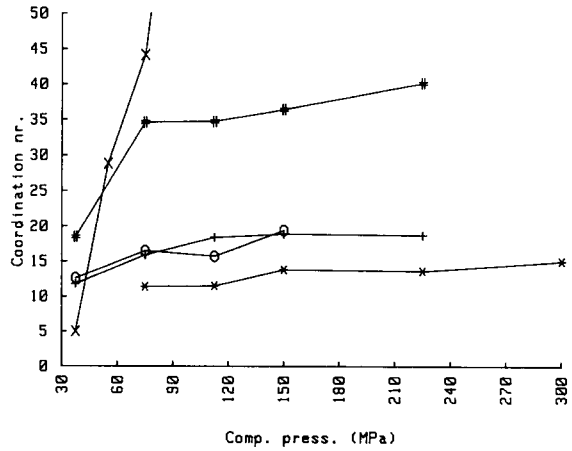

Fig. 2. Mean coordination number $\bar{k}$ as a function of compaction pressure for compacts of different types of lactose (see Table 6): (*), α-lactose monohydrate 100–125 μm; (+), anhydrous α-lactose 100–125 μm; (○), roller-dried β-lactose 100–125 μm; (×), 100% amorphous spray-dried lactose; (#), DC lactose 11 "spray-dried lactose".

Eqn. 13 is evaluated on the basis of the experimental results obtained by Vromans (1987).

Materials and Methods

The materials and methods are described in detail by Vromans et al. (1985, 1987a and b) and Vromans (1987). Compaction of tablets was carried out using a hydraulic press (Hydro Mooi Automation, Appingedam, The Netherlands). A weighed quantity of 500 mg was compressed at 55% relative humidity in a prelubricated die with flat-faced punches, having a diameter of 13 mm, at a compression speed of 2 kN/s. The crushing strengths of the tablets were measured 15 min after compaction with a diametral compression test apparatus (Schleuniger 2E). Tablet dimensions were determined using an electronic micrometer (Mitutoyo, Japan) with an accuracy of 0.001 mm. The mean tensile failure force F_c was applied to calculate the radial tensile strength σ_t with Eqn. 10.

The calculated porosity of the tablet was derived from data of its weight, volume and material density (α-lactose: 1.54 g/cm^3, β-lactose: 1.59 g/cm^3). The specific surface areas and Hg-porosities were obtained by mercury intrusion porosimetry (Carlo Erba series 200 porosimeter). The tablets were evacuated at about 10 Pa prior to the measurements for at least half an hour. The experimental results are compiled in Table 1.

In addition to the determination of specific surface area by mercury intrusion porosimetry, 4 lots of tablets of the main lactose types of Table 1 compressed at 37.5 MPa were analysed by the BET nitrogen adsorption technique (Quantasorb).

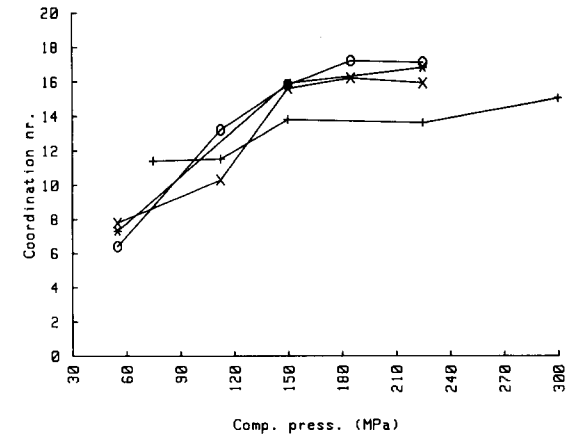

Fig. 3. Mean coordination number $\bar{k}$ as a function of compaction pressure for compacts of α-lactose monohydrate with different initial particle size (see Table 7): (*), 32–45 μm; (+), 100–125 μm; (○), 125–160 μm; (×), 315–400 μm.

The results of the specific surface areas are compiled in Table 2.

Tablets of different particle size fractions of α-lactose monohydrate and crystalline β-lactose with a diameter of 11.3 mm and a mass of 350 mg were prepared at different compaction pressures and analysed by gas permeametry according to the method described by Alderborn et al. (1985). These permeametry surface areas are compiled in Tables 3 and 4.

TABLE 5

Coordination numbers and geometrical arrangement of isometric spherical particles (Sherrington and Oliver, 1981)

Case	Geometrical arrangement	Coordination number
(1)	Cubic	6
(2)	Orthorhombic	8
(3)	Tetragonal-spheroidal	10
(4)	Rhombohedral	12

TABLE 6

Values for lactose compacts

Type of lactose	Compaction pressure (MPa)	Porosity (Hg) (%)	Crushing strength (N)	Surface area S_m (m^2/g)	$\bar{k}$	k^*	$\bar{x}$ (μm)
α-Lactose	75	16.8	20.6	0.49	11.4	18.7	8.0
monohydrate	112.5	15.6	33.4	0.79	11.5	20.1	4.9
(100–125 μm)	150	12.2	42.2	0.83	13.8	–	4.7
	225	10.0	62.8	1.26	13.6	–	3.1
	300	7.4	83.4	1.51	15.0	–	2.6
Anhydrous	37.5	20.7	34.3	0.79	11.8	15.2	4.9
α-lactose	75	18.5	72.6	1.24	15.9	17.0	3.1
(100–125 μm)	112.5	15.3	110.9	1.64	18.4	20.5	2.4
	150	12.3	147.2	2.12	18.9	–	1.8
	225	9.5	~ 216	3.14	18.7	–	1.2
Roller-dried	37.5	25.8	24.5	0.53	12.6	12.2 [1]	7.1
β-lactose	75	21.2	52.0	0.86	16.5	14.8	4.4
(100–125 μm)	112.5	16.4	69.7	1.21	15.7	19.2	3.1
	150	13.2	104.0	1.46	19.4	–	2.6
100% Amorphous	37.5	22.6	~ 10	0.53	5.1	13.9	7.4
spray-dried lactose	55	21.3	67.7	0.64	28.8	14.7	6.1
	75	19.1	106.9	0.66	44.1	16.4	5.9
	95	18.9	169.7	0.55	84.0	16.6	7.1
	115	12.5	~ 196	0.61	87.5	–	6.4
	150	8.3	> 200	0.56	> 97	–	7.0
	225	4.3	≫ 200	0.54	> 100	–	7.2
DC lactose 11	37.5	29.5	37.3	0.55	18.5	10.6 [1]	7.1
"spray-dried	75	20.4	73.6	0.58	34.6	15.4	6.7
lactose"	112.5	17.0	110.9	0.87	34.7	18.5	4.5
	150	13.9	147.2	1.10	36.4	–	3.5
	225	10.1	~ 220	1.50	39.9	–	2.6

[1] Eqn. 14 valid ($\epsilon > 0.25$).

Mean coordination number $\bar{k}$ calculated according to Eqn. 13, k^* according to Eqn. 14 and mean particle diameter $\bar{x}$ according to Eqn. 6 for lactose compacts with 500 mg mass and a diameter of 13 mm. The surface area was determined by mercury intrusion porosimetry.

TABLE 7

Values for α-lactose monohydrate compacts

Size fractions (μm)	Compaction pressure (MPa)	Porosity (Hg) (%)	Crushing strength (N)	Surface area S_m (m^2/g)	Tablet thickness (mm)	$\bar{k}$	$\bar{x}$ (μm)	σ_t (MPa)	σ_t^* (MPa)
32–45	55	24.5	16.7	0.62	3.237	7.3	6.3	0.25	0.41
	150	13.5	72.6	1.24	2.845	15.9	3.1	1.25	0.95
	225	11.1	98.1	1.59	2.729	16.8	2.5	1.76	1.25
100–125	75	16.8	20.6	0.49	3.001	11.4	8.0	0.34	0.36
	112.5	15.6	33.4	0.79	2.920	11.5	4.9	0.56	0.59
	150	12.2	42.2	0.83	2.770	13.8	4.7	0.75	0.64
	225	10.0	62.8	1.26	2.710	13.6	3.1	1.13	1.00
	300	7.4	83.4	1.51	–	15.0	2.6	–	1.23
125–160	55	18.6	10.8	0.46	3.021	6.4	8.5	0.18	0.33
	112.5	14.9	39.2	0.81	2.855	13.2	4.8	0.67	0.61
	150	12.4	51.0	0.88	2.778	15.8	4.4	0.90	0.68
	185	11.1	61.8	0.98	2.760	17.2	4.0	1.10	0.77
	225	9.7	71.6	1.14	2.710	17.1	3.4	1.29	0.91
315–400	55	16.4	9.8	0.34	2.933	7.8	11.5	0.16	0.25
	112.5	13.6	22.6	0.60	2.840	10.3	6.5	0.39	0.46
	150	11.6	37.3	0.65	2.751	15.6	6.0	0.66	0.51
	185	10.2	48.1	0.81	2.712	16.2	4.8	0.87	0.64
	225	9.3	55.9	0.96	2.680	15.9	4.1	1.02	0.77

Mean coordination number $\bar{k}$ calculated according to Eqn. 13, mean particle diameter $\bar{x}$ according to Eqn. 6, tensile strength σ_t according to Eqn. 10 and σ_t^* according to Eqn. 7 for the maximum coordination number $\bar{k} = 12$ for compacts of α-lactose monohydrate with different initial particle size with 500 mg mass and a diameter of 13 mm. The surface area was determined by mercury intrusion porosimetry.

Results and Discussion

Specific surface areas

According to the resolution power of the applied methods as well as possible systematic errors, different values for the specific surface areas are obtained. The critical evaluation of the methods used are not within the scope of this paper. A different value of specific surface area corresponds to a different mean size of a set of isometric equivalent spherical particles. A discussion of reasonable values for the specific surface area is difficult and only possible on a basis of hypothetical models concerning the compaction process and the properties of the powder compacted. An attempt is made using Eqn. 13 and applying the concept of coordination numbers.

Coordination numbers

The coordination number of isometric spherical particles depends on their geometrical packaging. Thus the coordination number is a discrete value and varies between 6 and 12 (see Table 5 and Fig. 18b, cases 1, 2, 5 and 6 in Sherrington and Oliver, 1981).

In case of a multidisperse powder system of porosity ϵ a mean coordination number k^* can be calculated substituting the powder system by monodisperse spherical particles with equivalent mean diameter $\bar{x}$:

$$k^* = \frac{\pi}{\epsilon} \quad \text{with } 0.25 < \epsilon < 0.5 \tag{14}$$

In case of compacts with $\epsilon < 0.25$ the above relation is not valid. Based on the geometrical model of a system of mean isometric spheres compacted,

TABLE 8

Values for lactose compacts

Type of lactose	Size fractions (μm)	Crushing strength (N)	Surface area S_m (m^2/g)	$\bar{k}$	$\bar{x}$ (μm)
Anhydrous α-lactose	24–32	55.9	1.48	10.3	2.6
	32–63	48.1	1.15	11.4	3.4
	63–100	43.2	0.98	12.0	4.0
	100–160	40.2	0.91	12.0	4.3
	160–200	39.2	0.86	12.4	4.5
	250–315	32.4	0.72	12.3	5.4
α-Lactose monohydrate	24–32	18.6	0.70	7.3	5.6
	32–63	17.7	0.52	9.3	7.6
	63–100	11.8	0.48	6.8	8.2
	160–200	8.8	0.36	6.7	10.9
	250–315	7.8	0.34	6.2	11.5
Roller-dried β-lactose	32–63	32.4	0.83	10.6	4.5
	63–100	29.4	0.72	11.1	5.2
	100–160	23.5	0.61	10.5	6.2
	250–315	25.5	0.62	11.2	6.1
Crystalline β-lactose	32–63	15.7	0.57	7.5	6.6
	63–100	14.7	0.42	9.5	9.0
	160–200	9.8	0.35	7.6	10.8
	250–315	6.9	0.33	5.7	11.5

Mean coordination number $\bar{k}$ calculated acording to Eqn. 13 and mean particle diameter $\bar{x}$ according to Eqn. 6 for lactose compacts with 500 mg mass and a diameter of 13 mm. The specific surface area was determined by nitrogen gas adsorption.

reasonable values for $\bar{k}$ should vary between ca. 5 and ca. 15. A deviation from these results indicates a lack of fit of the theoretical model (13) and/or an incorrect determination of the experimental values used such as critical specific surface energy γ^d or internal specific surface area. In addition, the estimation of the mean size $\bar{x}$ of the particles and the coordination number $\bar{k}$ as a function of compaction pressure give a valuable insight into the consolidation process (see Figs. 1–3). The calculated values for $\bar{x}$ and $\bar{k}$ are compiled in the Tables 6–10. In Table 6 the coordination numbers were also calculated according to Eqn. 14, but using ϵ-values between 0.15 and 0.3 for comparison purposes.

Conclusions

The results of Tables 6–10 show that the calculated values of the coordination number $\bar{k}$ depend critically on the value of the specific surface area used. Reasonable values are obtained on the basis of specific surface area determined by gas adsorption (BET-method) and mercury intrusion porosimetry for the lots of lactose types which show brittle fracture during compression. The lower values for the specific surface area determined by gas permeametry yield coordination numbers exceeding the value of 15. The results do not allow to discriminate which of the methods of the determination of specific surface area have to be preferred. The model (7) which was derived, takes into account only London dispersion forces as well as the fact that the compact is formed by discrete particles. It is evident that the latter condition is only fulfilled for brittle substances which do not show an important plastic deformation.

The mean equivalent particle size $\bar{x}$ of the particles compacted depends on the resolution power of the method of determination of specific surface area. As the junctions between the individ-

TABLE 9

Values for α-lactose monohydrate compacts

Size fractions (μm)	Compaction pressure (MPa)	Crushing strength (N)	Surface area S_m (m^2/g)	$\bar{k}$	$\bar{x}$ (μm)
24–32	50	24.0	0.29	28.0	13.4
	75	40.4	0.38	36.0	10.3
	100	52.4	0.53	33.4	7.4
	125	72.0	0.64	38.0	6.1
	150	98.6	0.83	40.2	4.7
32–63	50	–	0.21	–	18.6
	75	23.0	0.26	29.9	15.0
	100	40.8	0.34	40.6	11.5
	125	52.2	0.44	40.1	8.9
	150	62.4	0.65	32.5	6.0
63–100	50	10.5	0.15	23.7	26.0
	75	25.0	0.22	38.4	17.7
	100	35.4	0.29	41.3	13.4
	125	47.1	0.35	45.5	11.1
	150	56.9	0.43	44.8	9.1
100–160	50	8.7	0.13	22.6	30.0
	75	20.0	0.20	33.8	19.5
	100	27.1	0.22	41.7	17.7
	125	–	–	–	–
	150	45.5	0.39	39.5	10.0
160–200	50	–	0.10	–	39.0
	75	17.5	0.16	37.0	24.4
	100	23.4	0.21	37.7	18.6
	125	34.0	0.30	38.3	13.0
	150	40.6	0.36	38.1	10.8
200–150	50	12.0	0.09	45.1	43.3
	75	19.6	0.13	51.0	30.0
	100	27.8	0.22	42.7	17.7
	125	34.1	0.31	37.2	12.6
	150	42.6	0.32	45.0	12.2
250–315	50	11.5	0.07	55.6	55.7
	75	13.2	0.12	37.2	32.5
	100	18.4	0.18	34.6	21.6
	125	27.3	0.25	36.9	15.6
	150	32.0	0.35	30.9	11.1

Mean coordination number $\bar{k}$ calculated according to Eqn. 13 and mean particle diameter $\bar{x}$ according to Eqn. 6 for compacts of α-lactose monohydrate with different initial particle size with 350 mg mass and a diameter of 11.3 mm. The specific surface area was determined by gas permeametry.

ual particles simulate very fine pores, the methods with high resolution power (e.g. nitrogen gas adsorption) may lead to an overestimation of the surface area, because they cannot distinguish between interparticular and intraparticular pores.

In case of the gas permeametry no intraparticular pores are measured. However, it may be possible that the power of resolution is not high enough and/or that the results are biased due to systematic errors involved in the calculation of the specific surface area. It cannot be excluded that the surface areas determined by gas permeametry are the only correct ones and that the critical specific surface energy γ^d taken from the literature (Lerk et al., 1976) is an underestimation.

The theoretical model presented elucidates clearly the proportionality between crushing strength of brittle lactose tablets and the internal specific surface area (see Fig. 4). The mathemati-

TABLE 10

Values for crystalline β-lactose compacts

Size fractions (μm)	Compaction pressure (MPa)	Crushing strength (N)	Surface area S_m (m^2/g)	$\bar{k}$	$\bar{x}$ (μm)
32–63	75	34.4	0.31	37.5	12.2
	100	46.8	0.41	38.6	9.2
	125	58.6	0.74	26.8	5.1
	150	63.6	0.81	26.6	4.7
100–160	75	25.4	0.15	57.3	25.2
	100	36.8	0.24	51.9	15.7
	125	46.8	0.33	48.0	11.4
	150	57.2	0.45	43.0	8.4
160–200	75	16.4	0.12	46.2	31.4
	100	24.2	0.20	40.9	18.9
	125	–	–	–	–
	150	45.2	0.33	46.3	11.4
200–250	75	13.8	0.13	35.9	29.0
	100	24.0	0.17	47.7	22.2
	125	34.1	0.26	44.4	14.5
	150	44.0	0.30	49.6	12.6
250–315	75	18.6	0.14	44.9	27.0
	100	28.8	0.19	51.3	19.9
	125	38.8	0.28	46.9	13.5
	150	44.2	0.34	44.0	11.1

Mean coordination number $\bar{k}$ calculated according to Eqn. 13 and mean particle diameter $\bar{x}$ according to Eqn. 6 for compacts of crystalline β-lactose with different initial particle size with 350 mg mass and a diameter of 11.3 mm. The specific surface area was determined by gas permeametry.

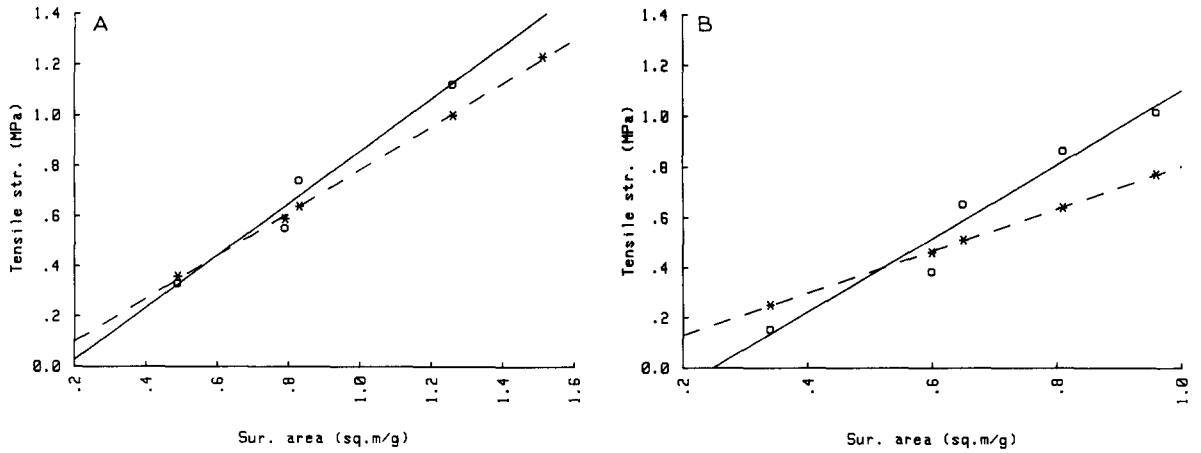

Fig. 4. a. Plot of tensile strength σ_t vs surface area S_m and σ_t^* vs S_m for compacts of α-lactose monohydrate 100–125 μm (see Table 7): (○), σ_t: slope = 1.04 MPa/m^2/g, intercept = −0.18 MPa, correlation coefficient = 0.9832; (*), σ_t^*: slope = 0.86 MPa/m^2/g, intercept = −0.07 MPa, correlation coefficient = 0.9995. b. Plot of tensile strength σ_t vs surface areas S_m and σ_t^* vs S_m for compacts of α-lactose monohydrate 315–400 μm (see Table 7): (○), σ_t: slope = 1.46 MPa/m^2/g, intercept = −0.36 MPa, correlation coefficient = 0.9749; (*), σ_t^*: slope = 0.84 MPa/m^2/g, intercept = −0.04 MPa, correlation coefficient = 0.9998.

cal model presented is not valid for substances which deform plastically during compaction such as amorphous spray-dried lactose.

The calculation of coordination numbers on the basis of a compact formed by equivalent spherical isometric (brittle) particles with the mean particle size $\bar{x}$ according to Eqn. 13 yield the right order of magnitude. The calculated values do not differ very much from the ones calculated by Hiestand (1985) using a different approach.

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