

Short Communication

Effect of Particle Shape on the Tensile Strengths of Powders

I. NIKOLAKAKIS and N. PILPEL*

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

(Received November 12, 1984)

Introduction

Quantitative relationships have been established between the tensile strengths, packing fractions and particle shapes of samples of iron oxide in the size range 0.15 - 0.7 μm and of beta copper phthalocyanine in the size range 0.02 - 0.08 μm . These are $\log T = 0.973\alpha P_F - 0.005$ with a correlation coefficient 0.854 for the iron oxides and $\log T = 1.271\alpha P_F + 0.367$ with a correlation coefficient 0.925 for the copper phthalocyanines.

Previous work has shown that the tensile strength T of an assembly of fine particles depends on their nature, packing fraction [1], moisture content [2], particle size and shape [3], temperature [4] and length of period of consolidation [5, 6].

Little quantitative work has been done on the specific effects of particle shape; this is due to the difficulty of sorting fine powders into different shape fractions when the particles are below about 80 μm in diameter [7].

To eliminate or control the effects of the other variables, two materials were chosen, each of which was available in a narrow size range, with different grades containing particles of widely different shapes. Their moisture level was maintained below 1 wt.%. Measurements of tensile strength at different packing fractions P_F were carried out at a constant temperature and at a fixed time after consolidation, in order to identify the individual and combined effects of particle shape and packing fraction.

*To whom correspondence should be addressed.

Experimental materials and methods

Seven grades of iron oxide in the size range 0.15 - 0.7 μm and five grades of beta copper phthalocyanine in the size range 0.02 - 0.08 μm were obtained from Bayer and Ciba-Geigy respectively. Their moisture contents were measured with a vacuum tester (Townsend and Mercer) and were less than 1 wt.%. The densities of the particles, ρ_s g cm^{-3} , were measured with a Beckman air comparison pycnometer (Beckman Instrument Model 930) and their specific surface areas, S_w $\text{m}^2 \text{g}^{-1}$, with a sorptometer (Perkin Elmer Model 212C), using nitrogen, with helium as the carrier gas [8, 9]. For the iron oxides, average values of particle length L μm and breadth B μm and hence of the elongation ratio $N = L/B$ were obtained from Bayer [10]. The corresponding values for the phthalocyanines were measured from photomicrographs of at least 200 particles from each sample, using a transmission electron microscope (Philips 301G).

The shape coefficients α of all the samples were then calculated from the expression

$$\alpha = \frac{\alpha_{s,a}}{\alpha_{v,a}} + N = S_w \rho_s d_e + \frac{L}{B} \quad (1)$$

This is a modified form of Heywood's expression [11], to include the elongation ratio of the particles*. d_e is the Heywood equivalent diameter =

$$\left(\frac{0.77 \times 4 \times L \times B}{\pi} \right)^{1/2} (\mu\text{m}),$$

$\alpha_{s,a}$ is the surface shape coefficient, which is a measure of the surface irregularities on the particles, and $\alpha_{v,a}$ is the volume shape coefficient, which is a measure of their geometric form [12]. The tensile strengths of the samples, T N m^{-2} , were measured at room temperature within approximately 15 min of consolidation to different packing fractions, in a split-plate tensile tester whose design and

*When shape is defined in this way, samples with the same geometrical form do not in general have the same values of α .

TABLE
Properties of the materials

Material and code	Geometric shape	Particle density ρ_s (g cm^{-3})	Particle diameter d_L (μm)	Elongation ratio N	Specific surface area S_w ($\text{m}^2 \text{g}^{-1}$)	Average particle shape coefficient α
Iron oxide	130	5.00	0.22	1.46	10.00	12.40
	180	5.10	0.70	1.37	2.68	10.94
	318	4.60	0.20	1.50	9.63	10.30
	686	4.80	0.15	1.34	15.00	12.16
	910	4.10	0.24	6.00	16.00	21.91
	930	4.10	0.40	4.00	15.50	22.67
	940	4.10	0.40	4.00	8.50	17.96
Beta copper phthalocyanine	1	1.74	0.05	3.12	71.00	9.30
	2	1.64	0.08	3.19	39.00	8.20
	7	1.67	0.03	3.37	56.50	6.20
	8	1.77	0.03	2.04	76.43	6.10
	9	1.69	0.02	1.60	56.36	3.50

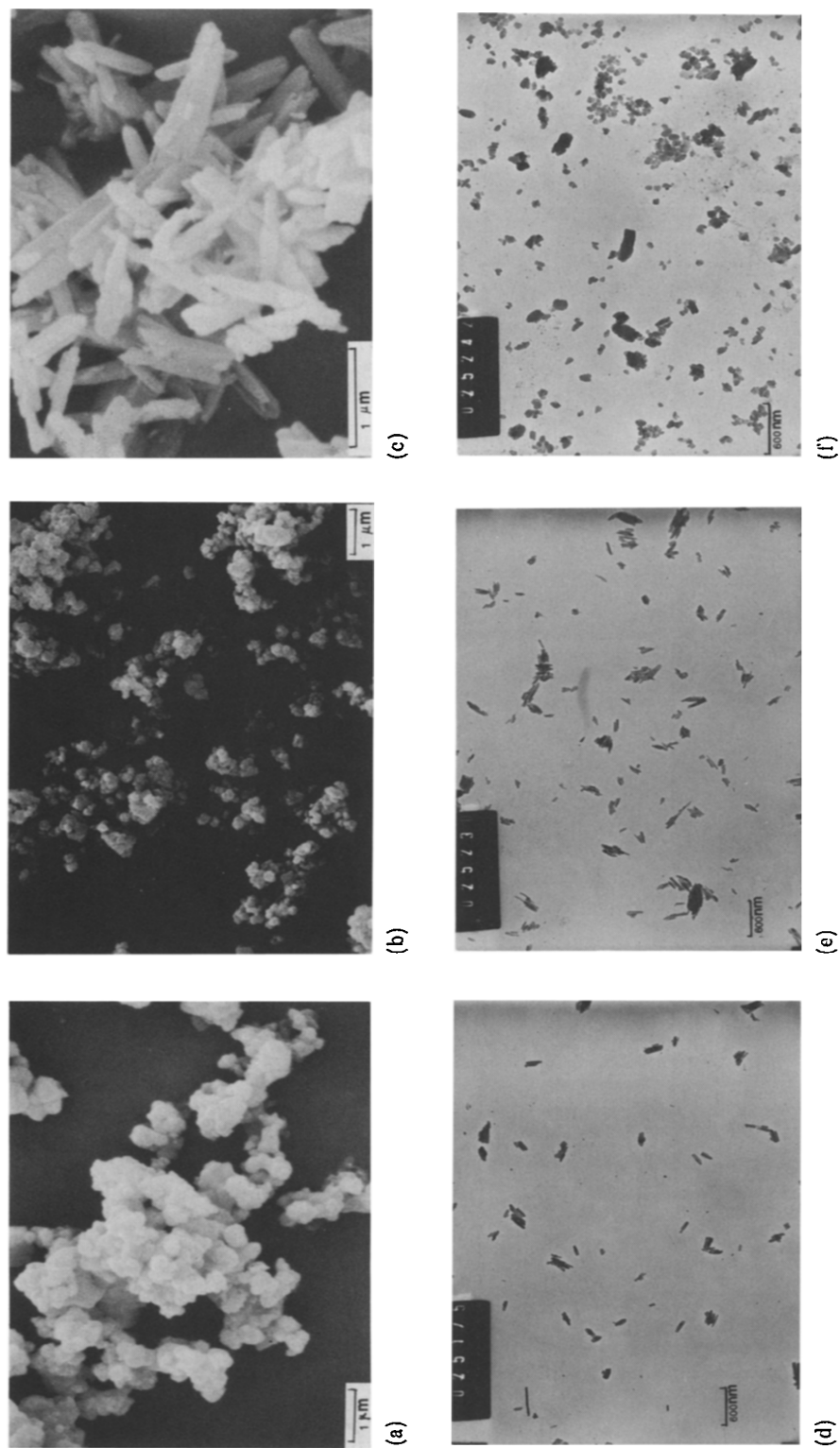
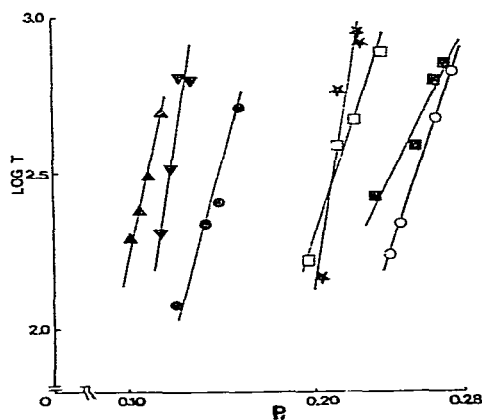


Fig. 1. Photomicrographs. Iron oxides. (a), 180; (b), 686; (c), 940. Beta copper phthalocyanines: (d), 2; (e), 7; (f), 9.

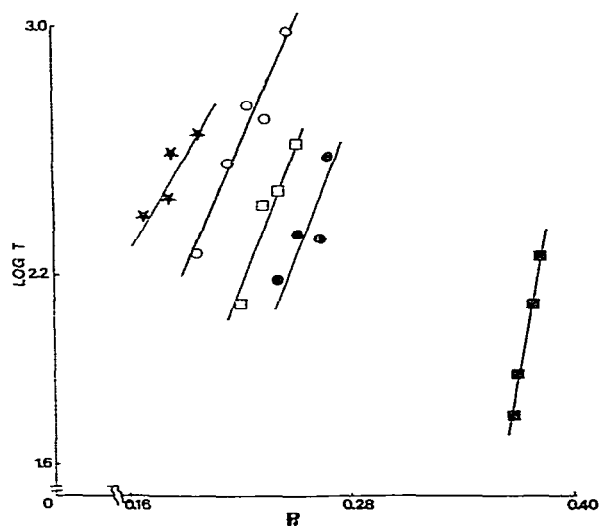
operation have been described previously [13].

Results and discussion

The table lists the physical and geometrical properties of the twelve samples. Figures 1(a) to 1(f) give representative photomicrographs, showing that the particles varied from spherical to acicular. Figures 2(a) and 2(b) present plots of $\log T$ versus packing fraction. It is seen that the results conform to the well-known relationship (1)



(a)



(b)

Fig. 2. Log tensile strength T versus packing fraction P_F . (a) Iron oxides: ★, 130; ▲, 910; ■, 180; ▼, 930; ○, 318; ●, 940; □, 686. (b) Beta copper phthalocyanines: ★, 1; ●, 8; ○, 2; ■, 9; □, 7.

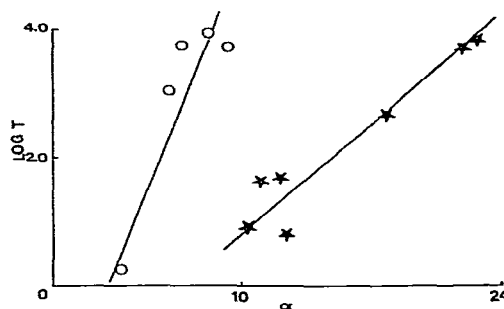


Fig. 3. Log tensile strength T versus shape coefficient α . ★, Iron oxides at $P_F = 0.16$; ○, beta copper phthalocyanines at $P_F = 0.32$.

$$\log T = AP_F + A_0 \quad (2)$$

where A and A_0 are constants for each material. Since the moisture contents of the powders were virtually the same and both materials had very narrow ranges of particle sizes, the effects of these two variables on T [2, 3] were eliminated.

Figure 3 shows the effect of the remaining variable α on the values of T for the iron oxides and copper phthalocyanines, at packing fractions of 0.16 and 0.32 respectively (chosen so as to involve minimum extrapolation of the $\log T$ versus P_F curves (Figs. 2(a), (b)). The relationship is similar to that in eqn. (2), i.e.

$$\log T = B\alpha + B_0 \quad (3)$$

where B and B_0 are constants.

It follows from eqns. (2) and (3) that $\log T$ should be a function of the product αP_F . This is confirmed in Figs. 4(a) and 4(b) where, allowing for the errors involved in deriving average shape coefficients for very fine particles [14] and in measuring tensile strengths [15], it is seen that the results can be reasonably described by two straight lines. The equations of the lines of best fit were

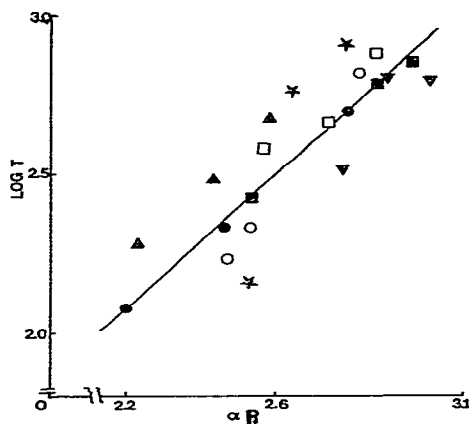
$$\log T = 0.973\alpha P_F - 0.005 \quad (4)$$

with a correlation coefficient 0.854 for the iron oxides and

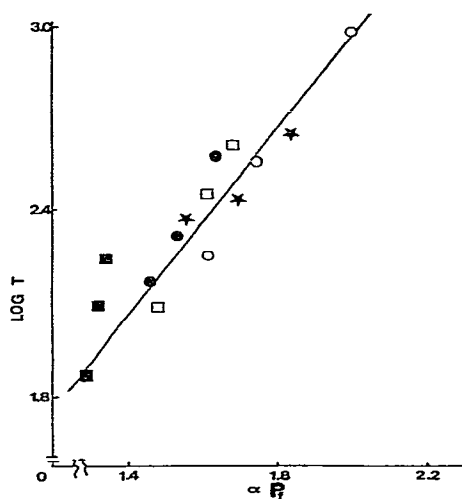
$$\log T = 1.271\alpha P_F + 0.367 \quad (5)$$

with a correlation coefficient 0.925 for the phthalocyanines.

Work currently in progress shows that similar relationships should be found between the tensile strengths of other powders and the



(a)



(b)

Fig. 4. Log tensile strength T versus product of shape coefficient and packing fraction αP_f . (a), Iron oxides: ★, 130; ▲, 910; ■, 180; ▼, 930; ○, 318; ●, 940; □, 686. (b), Beta copper phthalocyanines: ★, 1; ●, 8; ○, 2; ■, 9; □, 7.

shapes of their particles and that as previously inferred [2] (though not so far proven), shape effects on the values of T become increasingly

significant as the average size of the particles is reduced. This follows from the fact that the tensile strength of an assembly of particles is due to the contact that occurs between the asperities on their surfaces [15, 16], the amount of contact depending increasingly on shape as the particle size is reduced.

Acknowledgements

The authors wish to thank Bayer (Inorganics Division) and Ciba-Geigy (Pigments) for the gift of materials.

References

- 1 M. D. Ashton, D. C.-H. Cheng, R. Farley and F. H. H. Valentin, *Rheol. Acta*, **4** (1965) 206.
- 2 N. Pilpel and C. A. Walton, *J. Pharm. Pharmacol.*, **26** (1974) 1P.
- 3 R. Farley and F. H. H. Valentin, *Powder Technol.*, **1** (1967/68) 344.
- 4 P. York and N. Pilpel, *Mater. Sci. Eng.*, **9** (1972) 281.
- 5 H. M. Sutton, in G. D. Parfitt and K. W. Sing (eds.), *The Characterisation of Powder Surfaces*, Academic Press, New York, 1976, p. 107.
- 6 S. T. David and L. L. Augsburger, *J. Pharm. Sci.*, **66** (1977) 155.
- 7 K. Ridgway and R. Rupp, *Powder Technol.*, **4** (1971) 195.
- 8 T. Allen, *Particle Size Measurement*, Chapman and Hall, London, 3rd edn., 1981, p. 496.
- 9 S. Lowell, *Introduction to Powder Surface Area*, Wiley, New York, pp. 34, 42, 149.
- 10 Bayer U.K. Ltd, *Technical Data for Iron Oxide Pigments*, 1984.
- 11 H. Heywood, *Inst. Chem. Eng. Q. Bull.*, **25** (1947) 14.
- 12 N. Pilpel, *Paint Manuf.*, **39** (1969) 23.
- 13 M. D. Ashton, R. Farley, F. H. H. Valentin, *J. Sci. Inst.*, **41** (1964) 763.
- 14 J. R. Fryer, *The Chemical Applications of Transmission Electron Microscopy*, Academic Press, New York, 1979.
- 15 D. C.-H. Cheng, *Chem. Engng. Sci.*, **23** (1968) 1405.
- 16 F. P. Bowden and D. Tabor, *Friction and Lubrication of Solids*, Vols. 1, 2, Clarendon Press, Oxford, 1953, 1964.