Particle Characterization

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PARTICLE CHARACTERIZATION

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INTRODUCTION

The effect of particle size, shape, and surface on the behavior of a powder is continually being studied. In quality control of a powder, seldom is a given parameter known well enough to predict accurately overall behavior of a powder. Therefore, many particle parameters must be evaluated to determine the influencing factors, including width, length/width ratio, volume, surface area, reentrant surface, bulk density, compressibility, surface roughness, pore volume, degree of sphericity, etc., and their relation to extrudability, pressability, firing performance, etc. Determining these things is called powder or particle characterization.

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DISCUSSION

Powder Characterization

Raw powders will have the following analysis performed on them before formulation, detonator packing, pressing, etc.

I. Bulk Property Analysis

- A. Density - Determined by Helium - Air Pycnometer
- B. Bulk Density
- C. Tap Density
- D. Compressibility
- E. Surface Area

- 1. Weight-Specific Surface Area (cm^2/g)
- 2. Volume-Specific Surface Area (cm^2/cm^3)

Both weight and volume specific surface area are determined by the following:

a. Air Permeability or Air Permeametry

- (1) Fisher Sub-Sieve Sizer (S_o^P)
- (2) Blaine Fineness Tester (S_o^B)
- (3) Knudsen Flow Permeameter (S_o^K)

b. Microscopy

- (1) Zeiss Analyzer (S_o^Z)

c. Gas Adsorption

- (1) Perkin-Elmer Adsorptometer (S_o^A) (Dynamic Flow System)

In addition to specific surface area, average spherical diameter is calculated for each of the above determinations and pore volume is determined by gas absorption. Surface roughness is estimated by subtracting S_o^Z from S_o^P . Reentrant surface is determined by subtracting S_o^P from S_o^A .

F. Degree of Sphericity

$$\chi = \Sigma \frac{S_s}{\frac{S_p}{N}} \text{ where}$$

when $\chi = 1$ the powder consists of only spheres

S_s = surface area of a sphere of equal volume

S_p = surface area of the particle (determined by Zeiss)

N = number of particles

$$G. \text{ Index of Fineness} = IF = \frac{1}{\begin{array}{c} \text{arithmetic mean} \\ \text{of} \\ \text{equivalent spherical diameter} \end{array}} = \frac{1}{\bar{x}}$$

II. Particle Analysis

A. Sieve Analysis - Calculated distributions of the following:

1. Particle Size

- a. Weight % retained
- b. Frequency % retained

2. Statistical Parameter Distributions

- a. Surface area/particle
- b. Spherical diameter
- c. Volume/particle
- d. Cross-Sectional Area

For each of the above distributions, means, etc., are also calculated. This is further covered under microscopy.

B. Microscopy - Zeiss analysis is used to calculate the following parameter from dimensional measurements of individual particles, where the parameters are calculated according to particle shape.

1. Length
2. Width
3. Length/Width ratio
4. Volume
5. Surface area/Particle
6. Cross-Sectional Area
7. Equivalent spherical diameter

For each parameter, both frequency and weight distributions are calculated with the following statistical evaluation:

a. Powder limits

- (1) Range, and lowest and highest value
- (2) Mid-Range = $\frac{\text{lowest value} + \text{highest value}}{2}$
- (3) Mode = Most frequently occurring value

b. Distribution Means

- (1) Arithmetic Mean = $\bar{X} = \frac{\sum x_i n_i}{N}$
- (2) Geometric Mean = $\bar{G} = (x_1 x_2 x_3 \dots x_n)^{\frac{1}{N}}$ or

$$\log \bar{G} = \frac{1}{N} \sum (\log x_i)$$
- (3) Harmonic Mean = $\bar{H} = \left[\frac{1}{N} \sum \left(\frac{1}{x_i} \right) \right]^{-1}$

c. Measure of Dispersion

(1) Quartiles

- (a) Lower = Q_1 = the 25th percentile size
- (b) Middle = Q_2 = the 50th percentile size
- (c) Upper = Q_3 = the 75th percentile size
- (d) Percentile Estimate = $Q_E = \frac{Q_3 + Q_1}{Q_2}$
- (e) Semi-Interquartile Range = $Q_5 = \frac{Q_3 - Q_1}{2}$

$$(f) \text{ Kramer's Modulus} = K = \frac{\sum_0^{50} x_i g_i \text{ (or } n_i)}{\sum_{50}^{100} x_i g_i \text{ (or } n_i)}$$

(g) Range from Median

- [1] lower = Median to lowest value
- [2] upper = Median to upper value

$$(h) \text{ Median Deviation} = M = \sqrt{\frac{\sum \bar{x}_i^2 n_i}{N} - \bar{M}^2}$$

$$(2) \text{ Standard Deviation} = S = \sqrt{\frac{\sum x_i^2 n_i}{N} - \bar{X}^2}$$

$$(3) \text{ Variance} = V = \frac{\sum x_i^2 n_i}{N} - \bar{X}^2 \quad \text{or } S^2$$

$$(4) \text{ Coefficient of Variation} = \underline{V} = \sqrt{1 - \bar{G}/\bar{X}} = 1/2 V^2$$

$$\text{where } \underline{V} = \sqrt{\frac{1 - \bar{G}/\bar{X}}{0.5}} \quad \text{or } \frac{S}{\bar{X}}$$

$$(5) \text{ Harmonic Variation} = \underline{\underline{V}} = \sqrt{1 - \bar{H}/\bar{X}}$$

d. Measure of Distribution Skewness

$$(1) \text{ Degree of Symmetry} = S_M = \frac{\bar{M}}{\bar{X}}$$

- where $S_M = 1$ for normal distribution
- $= < 1$ for skewed left
- $= > 1$ for skewed right

(2) Range from mean = $\bar{X}$ - lowest value

(3) Coefficient of skewness = $\gamma_1 = \frac{\mu_3}{\bar{X}^3}$

with μ_3 = third moment about weighted mean $\bar{X}$

$$\text{with } \mu_r = \frac{1}{n} \sum_{i=1}^k f_i (x_i - \bar{X})^r$$

(4) Momental Skewness = $\beta = \frac{\mu_3}{2\sigma^3}$

$$\text{with } \sigma = \sqrt{\mu_2}$$

(5) Coefficient of Excess = $\gamma_2 = \frac{\mu_4}{\sigma^4} - 3$

(6) Kurtosis (Measure of Flatness) = $\beta_2 = \frac{\mu_4}{\sigma^4} = \gamma_2 + 3$

e. Green Harmonic Mean Diameter calculated from

6 $\frac{\text{volume}}{\text{surface area}}$; to have the following calculated:

(1) d_1 = arithmetical mean diameter $\frac{\sum n_i d_i}{N}$

(2) $d_2 = \frac{\sum n_i d_i^2}{\sum n_i d_i}$

(3) d_3 = used in determination of surface area $\frac{\sum n_i d_i^3}{\sum n_i d_i^2}$

(4) $d_4 = \frac{\sum n_i d_i^4}{\sum n_i d_i^3}$

(5) Δ = determination of surface area = $\frac{\sum n_i d_i^2}{\sum n_i}$

$$(6) \quad D = \text{determination of } N = \sqrt{\frac{\sum n_i d_i^3}{\sum n_i}}$$

$$(7) \quad N = \frac{1}{\rho_s V^1 D^3}$$

$$(8) \quad S_o^H = \text{specific surface area} = \frac{\sigma^1/V^1}{\rho_s d_3} \quad \text{or} \quad \sigma^1 \Delta^2_N$$

$$(9) \quad \text{Degree of Uniformity} = \bar{U} = \bar{d}_1 \frac{\sum \frac{n_i}{(\bar{v}^1 D^3)}}{\sum \left\{ \frac{n_i}{(\bar{v}^1 D^3)} \left[\frac{d_1}{(\bar{V}^2)} + 2(\bar{d}_1 - d_1)^2 \right] \right\}}$$

CONCLUSION

Many segments of the above analysis of a powder have been completed and used to study various relationships; e.g., particle size versus extrudability and vacuum stability, analysis of k factor and its influence on air permeability surface area, etc.

The determination of surface area by air permeability (Fisher Sub-Sieve Sizer) has been useful and widely used procedure by the AEC explosives laboratories. One of its most widely used applications is in determining specific surface area for detonator grade PETN. The Fisher Sub-Sieve Sizer (FSSS) popularity is primarily due to its easy, rapid analysis of a powder. Measurements by absorption of a gas at low temperatures usually give higher surface area numbers, often considered more accurate. Many explanations were made as to why air permeability measurements are lower than gas absorption. Presently many workers believe that air permeability's difficulties with irregular shaped particles were due to streamline or non-contact flow, which includes little of the area making up the cracks and pores within the body of porous particles. Others believe the shape of the particles influence the air flow through the bed; e.g., cylindrical particles placed parallel to the air flow offer less resistance than particles placed perpendicular to the flow. The influences of these factors are considered in the equations on which Gooden-Smith based their analysis from which the FSSS was designed.

The initial theory was based on Poiseville's equation for fluid flow through capillaries. Kozeny developed an equation, using Poiseville's equation, which described the flow of a fluid through a bed of divided material, from which Carman developed the Kozeny-Carman equation for determining surface area of a powder. From these experimentors and Henry Green, Gooden-Smith developed the air permeability instrument known as the Fisher Sub-Sieve Sizer.

Surface Area from Permeametry

Basically a permeability apparatus consists of a chamber containing the powder to be measured, a pump or other device with which a fluid is made to flow through the powder, and gages to indicate the rate of flow and the accompanying pressure drop across the chamber. The flow may be either streamlined or not. Surface area is calculated from consideration of the powder bed dimensions, the degree of packing, the properties of the flowing fluid, and the resistance to flow encountered.

Permeability indicates the surface area that contributes to the pressure drop. With streamline flow this surface area is the non-contact area over which the fluid passes and includes little of the area making up the walls of cracks and pores within the body of porous particles. Streamline flow results indicate what might be called the external surface area of particle materials. Liquids and gases, at or near atmospheric pressure, are primarily employed as the flowing fluids. Newer developments utilize gases at greatly reduced pressures. In the reduced pressure state the flow is considered molecular streaming or Knudsen flow where the resistance is due primarily to molecular collision with particles and passage walls (reentrant surface).

Streamline flow relations are primarily applicable to relatively coarse powders with a resultant surface area equivalent to an envelope surface area. Molecular streaming relations permit determinations for materials having a mean surface diameter down to $\sim 0.1 \mu$ with a surface area comparable to gas absorption or total surface area.

Theory of Air Permeability

Gooden-Smith¹ state, "It has been pointed out by Green² and by Carmen that, of the many kinds of average particle diameters for a powder, the most important is the average that is equal to the diameter of a sphere equivalent in specific surface to the sample as a whole. For spherical particles this is simply an average diameter by surface weighing; for particles of any shape it is twice the average normal radius by surface weighing. The value of this average diameter, either for a single particle or for a group, is six times the total volume divided by the total surface regardless of particle shape or size distribution."

Green expressed specific surface area as a surface area per gram of material. Expressing this in the form of a general equation it gives:

$$S_w = \frac{1}{\rho_s \left(\frac{\sum nV}{\sum nS} \right)} \quad (1)$$

S_w = Surface area/unit weight (cm²/gm)

ρ_s = Particle density (gm/cm³)

V = Volume of each particle (cm³)

S = Surface of each particle (cm²)

n = Frequency

When geometrical similarity exists it follows that if the particle volume is made proportional to the cube of some arbitrary diameter and the surface proportional to the same diameter, then the proportionality factors are constant for the entire mass of particles. Therefore, in equation 1 we

may substitute $V = \gamma'd^3$ and $s = \sigma'd^2$ where γ' and σ' are the proportionality constants. For this special class of materials, equation 2 is less general

$$S_W = \frac{\sigma'/\gamma'}{\rho_s (\Sigma nd^3 / \Sigma nd^2)} \quad (2)$$

than equation 1. Equation 2 holds, however, for any particle shape, for non-uniformity and for any fixed diameter with the only limitation being geometrical similarity.

In order to deviate from geometrical similarity we must restrict the particle diameters to a diameter which will be equivalent in each shape tested. The harmonic mean diameter d_m is equal to $6 V/S$ which gives,

$$S_W = \frac{6}{\rho_s (\Sigma dn_m / \Sigma nd_m)} \quad (3)$$

The diameter of a sphere, the edge of a cube, and the harmonic mean diameter of the three edges of a rectangular parallelepiped are each equal to $6 V/S$. This diameter is evidently a kind of "natural" one, for its introduction, as will be seen, simplifies matters considerably. At infinite uniformity, equation 3 reduces to the well-known expression for specific surface,

$$S_W = 6/\rho_s d_m \quad (4)$$

The next step behind the theory of air permeability is how can d_m be determined from the resistance offer to a flowing fluid by a column of packed particles of random shape.

Viscous Flow: Streamline Flow Permeametry

The equation describing the flow of a fluid through a bed of divided material was given by Kozeny³ and Fair and Hatch⁴. We shall use as a basis for derivation the hydraulic radius defined as the cross-sectional area of a conduit derived by the perimeter wetted by a fluid, the procedure used by Fair and Hatch. Thus, for a circular tube filled with a fluid, the hydraulic radius is:

$$Rh = D/4 \quad (5)$$

Rh is hydraulic radius

D is the diameter of the tube

For a packing of length L and porosity ϵ ,

$$Rh = \frac{\text{Cross-sectional area of flow}}{\text{Wetted perimeter}} \quad (6)$$

$$Rh = \frac{\text{Volume of voids}}{\text{Void (or particle) surface area}} \quad (7)$$

$$\text{with } V_t = V_s + V_v \quad (8)$$

where V_t is total volume

V_s is volume of solid

V_v is volume of voids

from which porosity is determined by the equation:

$$\epsilon = V_v/V_t \quad (9)$$

from this R_h may be found by the equation:

$$R_h = \frac{V_s}{S} \left(\frac{\epsilon}{1-\epsilon} \right) = \frac{1}{S_v} \left(\frac{\epsilon}{1-\epsilon} \right) = \frac{D_c}{4} \quad (10)$$

where S is solid surface area (cm^2)

S_v is surface area per unit volume of solid (cm^2/cm^3)

D_c is equivalent to the diameter of a capillary through the packing (cm)

$$\text{Since } S_w = \frac{6}{\rho_s dm}$$

$$\text{then } S_v = \frac{6}{dm} \quad (11)$$

$$\text{therefore if } \frac{D_c}{4} = \frac{1}{S_v} \left(\frac{\epsilon}{1-\epsilon} \right) \text{ then:}$$

$$\frac{D_c}{dm} = 2/3 \left(\frac{\epsilon}{1-\epsilon} \right) \text{ and} \quad (12)$$

$$dm = \frac{3D_c(1-\epsilon)}{2\epsilon} \quad (13)$$

A gas near atmospheric pressure and flowing at a moderate velocity moves along a channel in what is called viscous flow. This condition prevails in straight capillary tubes as well as along the irregular channels formed among confined particles. Therefore, D_c , the equivalent diameter of a capillary through the powder bed, must be found. Poiseuille flow for capillary tube can be used to determine D_c :

$$\frac{\Delta p}{L} = \frac{32\eta U_c}{g_c D_c^2}$$

Δp is pressure difference across powder bed (gm/cm²)

L is length of packing (cm)

η is viscosity of fluid (poises)

V_c is velocity through the capillary (cm/sec)

g_c is gravitational constant in cm/sec²

$$\text{then } D_c = \frac{\sqrt{L 32 \eta U_c}}{g_c \Delta p} \quad (15)$$

After finding D_c then dm can be found from equation 13 and S_w or S_v from equations 4 and 11, respectively.

To find other parameters pertaining to air-permeability surface area which leads to determining S_v and S_w with and/or without finding D_c the following equations are applicable.

When a fluid flows through a capillary tube because of a pressure difference at the opposite ends, the volume per unit time is given by the equation:

$$\frac{V}{t} = \frac{\pi r^4 \Delta p}{8 \eta l} \quad (16)$$

V is volume of flow per unit time (ml)

t is time of flow (sec)

r is radius of capillary tube (cm)

l is length of capillary tube (cm)

η is viscosity of fluid (poises)

Δp is pressure difference (gm/cm²)

The equation is valid only if the flow is laminar, which may not exceed flow Reynolds number 2000.

To determine the length of the capillary through the powder pack Poiseville equation can be used to give:

$$\ell = \frac{\pi r^4 \Delta p t}{8 \eta V} \quad (17)$$

In this equation ℓ is also equal to the tortuous path L_e through the packing.

If the flow is streamline, we may insert the value of D_c in the Poiseville equation and thus obtain for the pressure drop through the packing the equation:

$$\frac{\Delta p}{L} = \frac{32 \mu U_c}{g_c D_c^2} = \frac{2 \mu U_c S_v^2}{g_c} \frac{(1-\epsilon)^2}{\epsilon^2} \quad (18)$$

where μ is velocity of fluid (ml/sec)

g_c is gravitational constant (cm/sec²)

and if we use the formula

$$U_c = (U/\epsilon) (L_e/L) \quad (19)$$

where U_c is velocity through capillary (cm/sec)

L_e is length of tortuous path through the packing (cm)

L is length of packing (cm)

U is approach velocity (cm/sec)

$$\text{then } S_v^2 = \frac{g_c L}{2\mu U L_e} \left(\frac{\Delta P}{L} \right) \frac{\epsilon^3}{(1-\epsilon)^2} \quad (20)$$

and since $S_v = \rho_s S_w$ then S_w^2 would be:

$$S_w^2 = \frac{g_c L}{2\mu U L_e \rho_s^2} \left(\frac{\Delta p}{L} \right) \frac{\epsilon^3}{(1-\epsilon)^2} \quad (21)$$

Carman later showed that the surface area of powders forming a granular bed is related to the porosity and the permeability of the bed by the equations:

$$S_v = 14 \sqrt{\frac{1}{K_1} \left[\frac{\epsilon^3}{(1-\epsilon)^2} \right]} \quad (22)$$

where K is proportionately constants representing the permeability of the porous medium

Based on the fluid flow law, K_1 can be expressed by:

$$K_1 = \frac{Q_1 \eta L}{A \Delta p} \quad (23)$$

where Q_1 is the rate of the flowing fluid in ml/sec

A is the cross-sectional area of the porous medium in cm^2

η is the viscosity of the fluid in poises

Δp is the pressure difference driving the fluid through the medium in gm/cm^2

L is the thickness of the porous medium in cm

Also the relationship may be expressed by

$$K = \frac{g_c \epsilon^3}{5\eta S_v^2 (1-\epsilon)^2} \quad (24)$$

from which equation 17 can be expressed by

$$S_v = \sqrt{\frac{g_c}{kK\gamma} \left[\frac{\epsilon^3}{(1-\epsilon)^2} \right]} \quad (25)$$

where k is a proportionately constant of 5 ± 0.5

K is a permeability constant, representing apparent linear velocity per unit hydraulic gradient expressed in cm/sec

γ is Kinematic viscosity of the fluid in Stokes (cm/sec) (ratio of viscosity to density)

Carmen in his work with irregular particles showed that for many powders the ratio of L_e/L was ≈ 2.5 . The factor k used in equation 25 is called the aspect factor and found by equation:

$$k = 2 \frac{L_e}{L} = 5 \pm 0.5 \quad (26)$$

In this equation Carmen was concerned with the capillary forming the tortuous path which is a function of shape; but means of determining shape for irregular particles is extremely difficult to achieve.

Fowler and Hertel⁵ have also pointed out that the value of k depends upon both the material used and the favored orientation of any particles, the orientation, in turn, being related to the porosity. They show the value of k to be $\approx$ equal to

$$k = \sim \frac{3}{(\sin^2 \phi)_{av}} \quad (27)$$

where $(\sin^2 \phi)_{av}$ is the mean of the sin of the angle between the direction of over-all flow and the normal of the particle surface elements.

Fisher Sub-Sieve Sizer

Gooden and Smith changed the equation for the use with air currents by replacing in the equation

$$S_v = \sqrt{\left(\frac{g_c}{kK_Y}\right) \left[\frac{\epsilon^3}{(1-\epsilon)}\right]} \quad (1)$$

K_Y with $K_2\eta$ in which η is viscosity in poises (gm/cm/sec) and K_2 is permeability expressed as apparent linear velocity per unit pressure gradient (cm⁴/gm/sec). By apparent linear velocity is meant the volume rate of delivery of air from the apparatus at atmospheric pressure divided by the internal cross-sectional area of the sample tube. By substituting for S_v the equivalent diameter d_m , and expressing K_2 and η in terms of the observational data required for their determination, simplifying terms and changing the unit of diameter there is obtained the formula

$$d_m = \frac{60000}{14} \sqrt{\frac{\eta C \Delta p \rho L^2 M^2}{(V \rho - M)^3 (P - \Delta p)}} \quad (2)$$

where d is average diameter in microns

η is viscosity of air in poises (dynes-sec/cm²)

C is conductance of the flowmeter resistance in cm³/sec/unit pressure (g/cm²)

ρ is density of sample in gm/cc

L is length of height of the compacted sample cm

M is mass of sample in grams

V is apparent volume in cc of compacted sample

P is overall air pressure in grams/cm²

Δp is pressure difference in gm/cm² across flowmeter resistance

therefore;

If the sample weight is standardized at a value numerically equal to ρ, then the equation can be simplified to the form

$$dm = \frac{cL}{(AL-1)^{3/2}} \cdot \sqrt{\frac{p}{P-\Delta p}} \quad (3)$$

where c = an instrument constant that combines factors in equation 2

$$c = \frac{60000}{14} \cdot \sqrt{\eta C} = (3.80)$$

If the flowmeter resistance is a capillary tube of suitable dimensions, C is given by a simple form of Poiseville's equation

$$C = \frac{\pi r^4 g}{8 \ell \eta} \quad (4)$$

where r is radius of capillary

ℓ is length of capillary

g is gravitational constant

η is viscosity of air

By the expedience of using a sample weight equal in grams to the control density of material, packing the sample to a known degree, selecting and fixing several of the variables in the equation, it may be simplified to the extent that the average particle diameter is indicated by only the value of P;

i.e., as far as the instrument is concerned, by the height of a column of liquid in a glass tube. In the Sub-Sieve Sizer it is not necessary to make an actual measurement of the height of the liquid column. Instead, by proper use of the calculator chart, the average particle diameter and given porosity may be read directly from the chart.

$$dm = \frac{6 \times 10^4}{\rho S_w} = \frac{6 \times 10^4}{S_o^P}$$

$$\text{therefore; } S_o^P = \frac{6 \times 10^4}{dm_p} \quad (5)$$

where dm is the average diameter in μ

S_o^P is the specific surface area

EXPERIMENTAL

Samples of PETN which varied greatly in distribution and shape were measured by the Zeiss analyzer to see their effects on the surface area determined. The 25 samples' surface area were run in duplicates. The following simple correlations with surface area also measured by FSSS were calculated:

<u>Parameter</u>	<u>Correlation Coefficient</u>
Average length	+ .88974
Average width	- .29001
Average volume	+ .46565
Average area/particle	- .33731
Average cross-sectional area	+ .07208
Average spherical diameter	- .66837
Average L/W ratio	- .66837

Twenty-seven powders with irregular shapes and specific surface areas determined by gas absorption and FSSS ranged from 1714 to 27230 cm²/g. Results are shown in the following table.

Sample	Fisher Sub-Sieve Sizer S_o^P (cm ² /gm)	Fisher Av. Particle Diameter (μ)	Gas Absorption S_o^A (cm ² /gm)	$S_o^A - S_o^P$ (cm ² /gm)
8073	6519	5.40	8822	2303
8075	6918	4.90	7937	1019
8075-2	5926	5.72	9058	3132
8121-03	5794	5.85	8785	2991
8121-06	5467	6.20	6101	634
8148	6000	5.65	7903	1903
8306P	6186	5.48	7968	1782
83060	4808	7.05	6410	1602
8320	6519	5.20	9088	2569
1069-140	6141	5.52	8284	2143
1069-146	6119	5.54	9302	3183
1069-154	6108	5.55	8718	2610
1069-160	6277	5.40	10365	4088
1069-167	7369	4.60	11041	3672
1069-174	6032	5.62	8700	2668
1069-181	6420	5.28	8246	1826
1069-188	6336	5.35	8817	2397
1069-195	6520	5.20	8759	2239
1069-202	6190	5.48	9360	3170
1069-210	6220	5.45	9458	3208
1069-230	6301	5.38	8410	2109
8220	19939	1.70	27230	7291
5-43-1	1225	27.6	1786	561
5-43-8	2515	13.6	2856	341
5-43-11A	1244	27.4	1714	470
5-43-11B	1321	25.8	2212	881
5-43-11C	1311	26.0	2062	751
Total				
27 Samples				61543
Average Deviation				2279

Extex

Many parameters of a powder have been analyzed and used in the extrudability of Extex study, as determined by a Rossi-Peakes instrument.

<u>Analysis</u>	<u>Number of Observations</u>	<u>Correlation Coefficient</u>
1. Fisher Sub-Sieve Sizer (S_{ϕ}^P)	60	+0.63766
2. Gas Absorption (S_{ϕ}^A)	25	-0.77589
3. Zeiss Average Width	25	-0.66665
4. Zeiss Average Volume	25	-0.66087
5. Zeiss Average Area/Particle	25	-0.80391
6. Zeiss Avg. Cross-Sectional Area	25	-0.73072
7. Zeiss Average Length	25	+0.43096

Since the significance of these correlations are above 0.999 cm (except the last, which is ~0.98 cm) the relationships to the problems of extrudability appear evident. When this study was made, the only calculated means available was Zeiss arithmetic. Further analysis of distribution skewness, geometric and harmonic means, etc. may lead to a better understanding of problems connected with the extrudability of Extex.