When Powders Fail To Flow
or What is a Normalized Flow Function

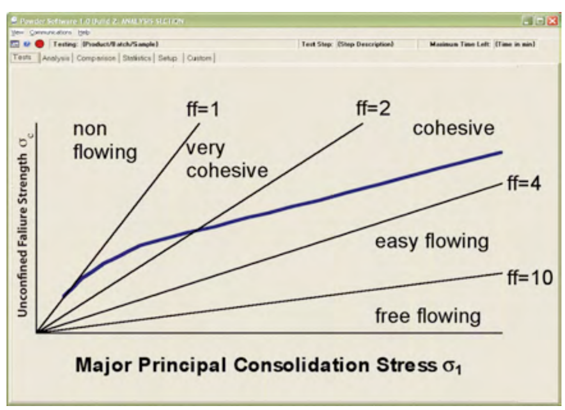
There are many traditional measurement methods for characterizing the "flowability" of powders: angle of repose, flow cup, tap test. Practitioners know that the information may not be useful some of the time, but experience helps to separate the meaningful test results from those that may be suspect. Examples of "flowability" for angle of repose measurements may look like the table on the left.

Flow Property	Angle of repose (degrees)
Excellent	25-30
Good	31-35
Fair (aid not needed)	36-40
Passable (may hang up)	41-45
Poor (most agitate, vibrate)	46-55
Very Poor	56-65
Very, Very Poor	> 66

Compressibility (Carr Index)	Flowability
5-12	Free Flowing
12-16	Good Flow
18-21	Fair
23-35	Poor
33-38	Very Poor
> 40	Extremely Poor

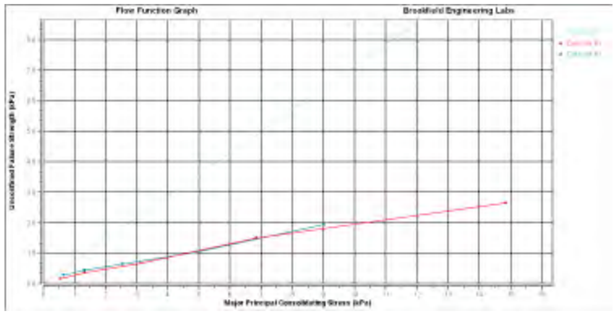
Examples of "flowability" using the Carr Index, which is the numerical value calculated from a "Tap Test", are shown in the table above on the right. (A full cylinder of powder is tapped multiple times and the decrease in the column height of powder is measured. The density value for the full column is subtracted from the "tapped" density value; the result is divided by the "tapped" density value.)

A test method that is gaining in practice is the Shear Cell which measures the sliding friction between powder particles during flow. (See example on the left of Powder Flow Tester) The resulting data is called "Flow Function" which can be used to rate powder flowability. The following graph shows an example of the Flow Function.



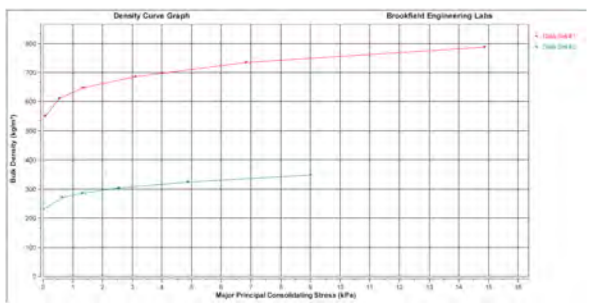
But powder is a very challenging and tricky product when you try to predict flow behaviour. This is due to the complex ways in which the particles physically interact, taking into account the surface type and shape, as well as the density. Using just one parameter to characterise the flowability of a powder can sometimes give inconsistent results or ever rank powders in the wrong order.

To address this concern, the shear cell method incorporates more than one parameter to characterise powder flowability. Take two powder materials, for example, that might appear to have the same flowability; looking at the below flow function graphs, you would say that they are indeed very similar

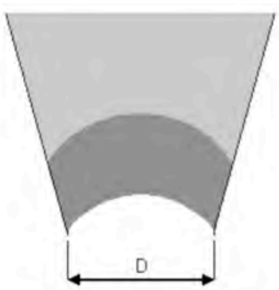


If we were to superimpose the standard flow indices shown in the initial Flow Function graph, you can see that both materials have a similar flow function and would be classified as "easy flowing". Taken a step further, if we take the flow index at 10 kPa, both have a flow index of 0.19 as reported in the following table.

The logical conclusion is that both of these materials have the same flow behaviour. However if we look at the results in more detail we can see that the bulk density for each sample is very different in the below graph.



One of the key factors that causes bad or erratic powder flow behaviour is a blockage due to arching. Below you can see the calculation for predicting the arch a powder can potentially achieve.



$$D = \frac{2 \cdot \sigma_C \cdot 1000}{\rho_B \cdot g}$$

{Eq. 1 Arching Dimension for conical hoppers}

$$D = \frac{\sigma_C \cdot 1000}{\rho_B \cdot g}$$

{Eq. 2 Arching Dimension for plane (wedge) hoppers}

Where:

D = Arching Dimension (m)

σ_C = *Critical Stress* (kPa)

ρ_B = *Critical Density* (kg/m³)

g = Acceleration of Gravity (m/s²)

Looking at the equation you will note that the Critical Stress and Critical density are the two variables in the equation. For our example the critical stress for both samples is very similar, 0.128 and 0.136 kPa. This very small difference in value will have little effect on the results from the equation. However, if we look at the critical density, this value is very different for each sample, 546.3 and 244.4 kg/m3. This will have a significant effect on the calculations for the arching dimension.

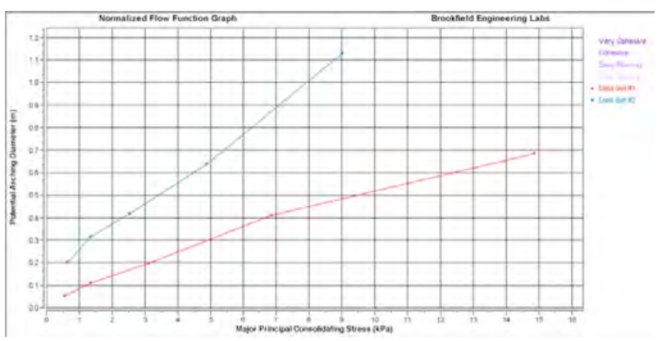
Sample 1 has an arching dimension of 0.009m and Sample 2 has 0.133m as shown in the next table.

Results:

Data Set #	Arching Dimension (m)
1	0.009
2	0.133

So although these powders have very similar flow functions (cohesion strength), Powder 2 is considerably lighter than Powder 1; because Powder 2 does not have as much self weight, it is more likely to create an arch, which will cause poor or unreliable flow.

The shear cell software goes a step further by graphing these results for the “Normalized Flow Function” in a very meaningful way. By simply adjusting the Y axis in the software to show the arching dimension as a function of consolidation stress, the difference in “flowability” for the two powders becomes very obvious, as shown in the following graph. By integrating the effect of the density of the powder against its own strength, the analysis shows a proper explanation for what happens in real life experience when powder “fail to flow”.



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