Mercury Scientific has developed testing proceedures to study the flow properties of powders and granular materials. Thes proceedures allow users of Mercury Scientific instruments to measure all aspects of the flow behavior of their materials. The data produced by these tests is useful for formulating powders, predicting powder behavior and quantifying powder quality.

Introduction

The Nature of Powders

Powders are made up of a mixture of solid particles and gas. The solid particles typically range from a few millimeters down to nanometer sizes. The gas between the particles is typically air. Due to the dual nature of powders, powder flow properties are produced by the interactions between the powder's particles and the gas surrounding them. Therefore the nature of the powder particles and the ratio between the solid and gas phases in the powder both effect the material's flow behavior.

In a simple analysis, the higher the solids ratio in a powder's make-up, the more it will behave like a solid. Contrarily, the more gas in a powder’s makeup, the more liquid like or even gas like its behavior will be. The problem with this is that the ratio of solids to gas in a powder is rarely constant and can change dramatically depending on how the powder is handled.

		
Storage Container solid to gas ratio lowest	**Loose Pile** solid to gas ratio medium	**Flowing** solid to gas ratio highest

In addition, the solid portion of a powder can change and also become charged. This makes studying and controlling powder behavior much more complex that controlling the behavior of solids, liquids or gases.

Powders and granular materials are also unique in terms of industrial materials in that they can remember their stress history. A powder will change depending on how it is handled and stored. For example, if a powder is stored in an industrial tote containing a 2 ton mass, the gas in the powder will be removed (compressibility) and the powder particles may form large particles (agglomerates) due to the pressure acting on the particles. If stored long enough in this way, the powder may actually become a solid (caking). When the pressure is removed, the powder may or may not go back to its original condition before storage.

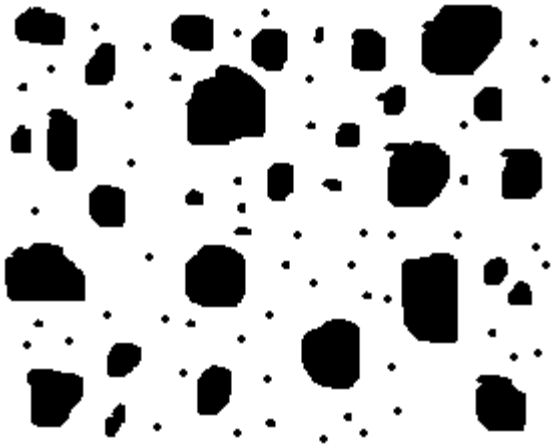
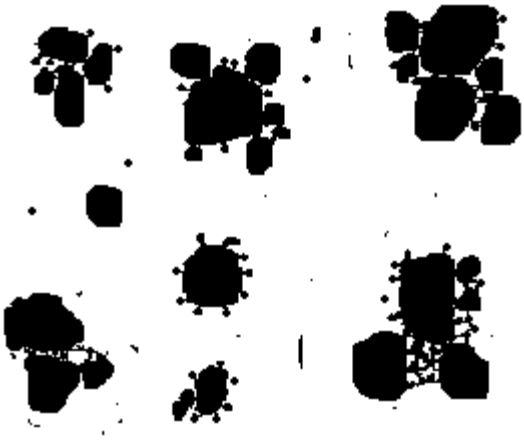
Powders with severe memory effects

This does not happen with other industrial materials. For example, a liquid can be stored at low or high pressure and be completely unchanged when the pressure is removed. The powder memory effect makes testing and controlling powder behavior even more complex.

Powder Micro-Structure and Macro-Structure

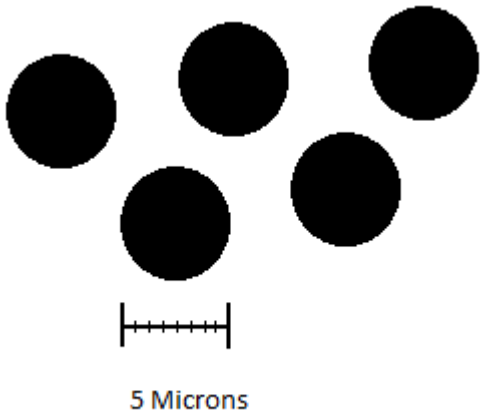
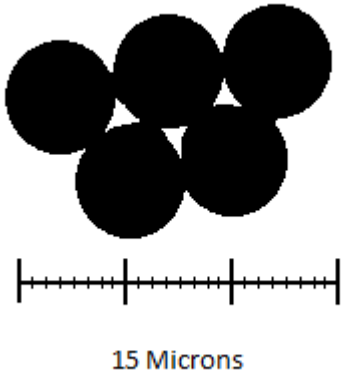
The structure of the particles or groups of particles making up the powder when it flows is referred to as the micro-structure of the powder. Powder micro-structure can be simple or complex. For simple powders systems, the micro-structure is simply the individual particles making up the material. This micro-structure is defined by the size of the particles. When the powder flows, the particles in the material flow as discrete individual particles.

In complex powder systems, the micro-structure is defined less on the individual particles making up the powder and more on groups of particles. These groups of particles are variously labeled as aggregates, agglomerates, clusters, or clumps. When a complex powder flows, it will flow as a combination of individual particles and groups of particles.

	
Simple micro-structure powder particles flow as individual particles	**Complex micro-structure** powder particles flow as groups of particles

In reality, most powders are complex systems because powders rarely flow as individual particles. The reason is that powder particles easily form micro-structure when they flow due to surface, electrical, and gravitational forces. We refer to the size of the particles in a flowing powders as the effective particle size. The effective particle size is always larger than the particle size of the individual particle

constituents making up the powder. This effective size is what typically controls the behavior of the powder. Unfortunately, the effective particle size of a powder is easily changed by handling and storage.

	
Individual Particle Size	**Effective Particle Size**

When powders are not moving, the micro-structure of the powder interacts and creates bonds to form what is referred to as the macro-structure of the powder. Theses bonds can be weak or strong depending on the nature of the solids making up the powder and the pressure acting on the particles. Powders with weak macro-structure cannot support themselves and form conical piles when unconfined by storage containers. Powders with strong macro-structure can support themselves and will form steep walled piles and will retain the shape of their container.

Powder States

Powder flow properties can be divided into three basic states based on the ratio of solid to gas in the powder and on the stresses acting on the powder. The main powders states are consolidated, unconsolidated, and fluidized.

In the consolidated state, powder particles are forced together by pressure. This pressure can be due to the height of the powder bead itself or from external conditions.

In the unconsolidated state, powder particles are not subject to consolidating pressures and can move freely.

In the fluidized state, the powder mass becomes aerated and particles are separated by larger and larger distances. This aeration can be a result of gas pressure applied externally to the powder or a result of high flow speeds.

Consolidated State	Unconsolidated State	Fluidized State
Static – particles not moving	Static or Dynamic	Dynamic – particles moving
When compressed, powders behave like solids and can even become solid under large pressures	Between consolidated and fluidized states, powders can exhibit both solid-like and liquid-like properties	When air is injected between a powder's particles, the powder can fluidize and behave like a liquid

In between consolidated and unconsolidated states, powders can be in semi-consolidated condition when aggregates, agglomerates, and clumps have formed micro-structure causing local areas of consolidation in an unconsolidated powder. In between unconsolidated and fluidized states, powders can be semi aerated and contain areas of low and high density.

Powders change their state depending on handling energy and storage conditions. These changes can be transient and reversible and the powder will return to its previous condition when the handling energy is reduced or the powder is removed from storage. Typically, however, powders have a memory effect and changes due to handling energy and storage are not reversible. These non-reversible changes including caking, clumping, agglomeration, de-agglomeration, particle attrition, and long term aeration.

Dynamic and Static Flow Tests

Powder flow tests fall into two categories: dynamic tests and static tests. In dynamic tests, powders are tested as they are flowing. These tests generally measure powder micro-structure and changes in

powder behavior due to changes in its the gas-solids ratio. Static tests measure powders that are not flowing and are under consolidation forces. These tests generally measure powder macro-structure. The Revolution Powder Analyzer is a dynamic powder flow testing device while the Evolution Powder Tester is a static powder flow measuring device. Both systems measure powder properties in various states and how they change as the powder moves between the consolidated, unconsolidated, and fluidized states.

	
Evolution Powder Analyzer measures powder strength after compression	**Revolution Powder Analyzer** measures powder flowing in a rotating drum

Instantaneous and Stability Tests

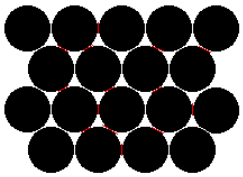
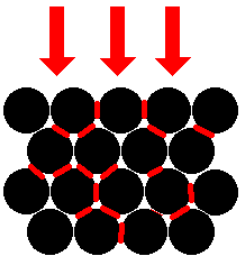
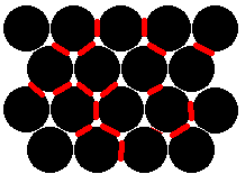
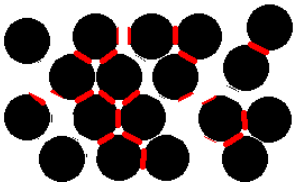
Instantaneous powder tests measure powder properties as they currently are in the test powder. Stability tests apply stresses to the samples to determine if powders change with storage, shear forces, aeration, etc. Instantaneous tests are also used to test powder stability when powders are subjected to external stresses before testing (temperature, pressure, humidity, shear).

A large percentage of powder flow problems are caused by instabilities in powders after storage and processing. For this reason, it is very important to know and simulate the storage and processing

conditions a powder will be subjected to as it is stored and used. The main causes of powder instability are pressure, humidity, temperature, shear, and impact.

Pressure acts on a powder by pressing powder particles together. This pressure can come in many forms. The most prevalent source of pressure is the powder mass itself. In a storage container, pressure is created by the weight of material over an area of powder. This pressure is a gradient that increases with the depth of the powder bed. For most applications, the maximum pressure is used for testing purposes. For example, for a typical 2 ton industrial tote, the bed pressure will be from 5-10 kPa depending on the density of the powder. This pressure is calculated by multiplying the mass of material in the tote times the acceleration of gravity and dividing by the bottom area of the tote. In some storage facilities or during shipping, totes are double stacked meaning the pressure will by also doubled.

For some powders this pressure causes irreversible changes in the powder particles. These changes include increases in the effective particle size due to agglomeration and caking, decreases in particle size due to fracturing of particles, and shape changes to to non-elastic compression. Time, temperature, and humidity play very important roles in the degree to which pressure will change a powder. Typically the longer a powder is under pressure, the higher the temperature, and the higher the humidity, the more the powder will be affected by the pressure.

			
Unconsolidated loose bonds between particles weak macro-structure	**Consolidated** pressure creates strong bonds between particles strong macro-structure	**After Consolidation** bonds must be broken for powder to flow -yield strength strong macro-structure	**On Flow** powder breaks along weakest bonds- strong agglomerates remain macro-structure becomes micro-structure

Shear forces during mixing and handling act on a powder by causing powder particles to smash and rub against each other. These interactions can have many unwanted effects on the the powder. Common

effects include attrition, agglomeration, shape changes, surface changes, and segregation.

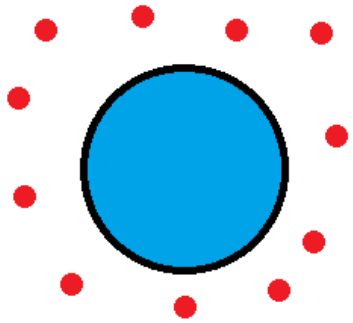
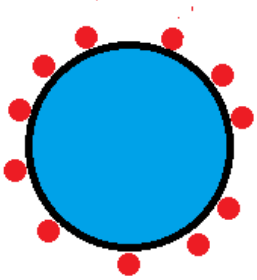
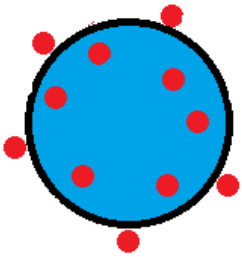
Attrition is the breakdown of particle size. This is typical for non-round particles. As the non-round particles are exposed to shear, long particles break into smaller particles along their lengths and the corners of cubical particles break off to create small particles (fines and dust). In effect the particles are grinding themselves into smaller particles. This is very common for flow agents which are typically made up of hard, friable particles.

		
Original Particle rough shaped	**Weak Spots** edges are weaker than particle as a whole	**Attrition** breakage on handling creates fines and rounder particle

Agglomeration is the bonding of two or more particles together as the hit against each other. There are many forces involved in agglomeration including van der waals forces, electrical forces, and cohesive forces.

Shape changes in particles can be caused by attrition, agglomeration or non-elastic impacts.

Surface changes include smoothing or roughing the surface of particles or embedding one group of particles in another. For example, if a flow agent has been added to a powder, adding shear force to the powder then change the activity of the flow agent by embedding it inside particles where it will no longer be effective. Flow agents only improve flow when they are on the surface of the powder particles.

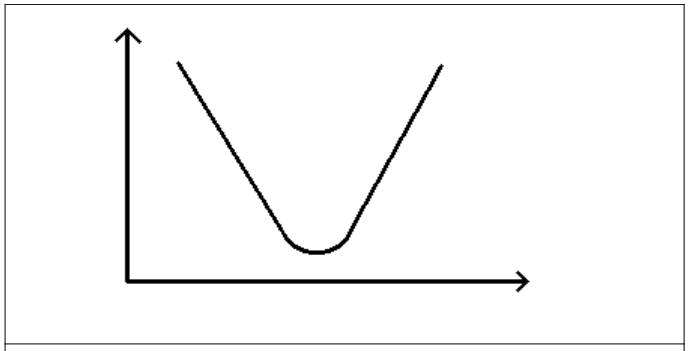
		
Early In Mixing particles and flow agents separate – flow poor	**After Shear Mixing** flow agent adheres to surface of particle – flow optimum	**Too Much Shear** flow agent embeds in particle – flow poor

Impact is another cause of powder instability. As particles move through high speed equipment, they impact against the walls of pipes, containers, and handling equipment. These impacts weaken and break particles into smaller particles.

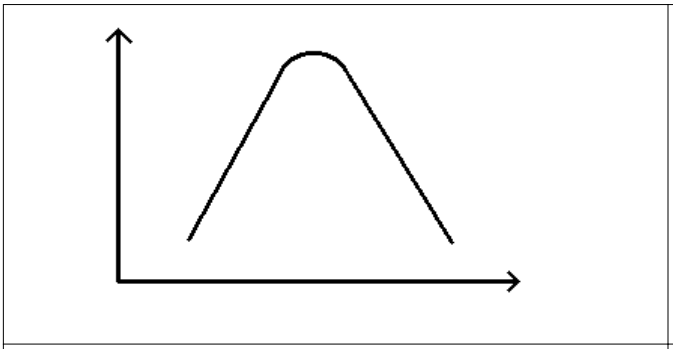
The U-Shaped Curve

As can be seen from the above sections, powders and granular materials are very complex systems and there are many factors that determine their behavior. Unfortunately the changes in powder behavior due to these factors are often non-linear. Many times powder behavior is U shaped (concave), reverse U shaped (convex), or both with regard to controlling parameters. The sharpness of the sides, the sharpness of the transition area and the symetry of the behavior can vary greatly from powder to powder.

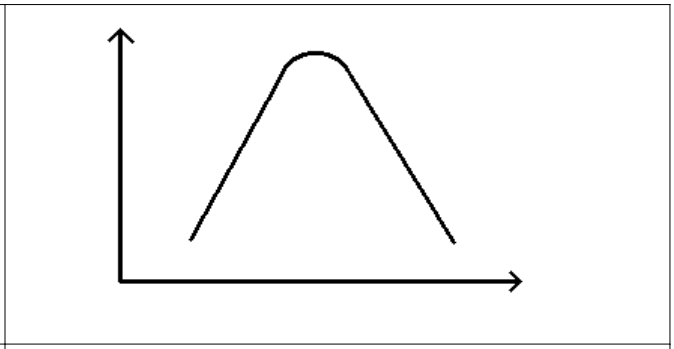
For these situations, it is critical that the behavior curve is well understood to avoid abrupt changes in powder properties. For example, if the powder is mixed to a low point in a flowability versus mixing curve then any additional mixing due to powder handling will only make the powder flow worse. Better to be at the point where additional mixing will improve the flow or leave it unchanged.



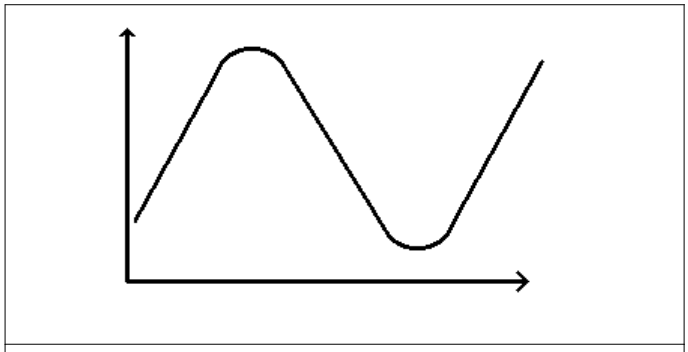
Unconfined Yield Strength verus Mixing Time



Unconfined Yield Strength verus % Moisture



Packing Density versus Particle Shape



Avalanche Energy verus % Flow Agent

No Shear Testing Techniques

In order to achieve meaningful results, powder flow tests should not change the sample being tested. This is the only way to measure both original powder properties and powder memory effects. As we have seen, shear forces applied to powders can change their nature by changing the gas to solids ratio in the sample in addition to changing the micro-structure of the powder itself. Shear can also eliminate history effects and make it impossible to study them.

Mercury Scientific Inc offers two instruments that measure powder flow properties without applying shear forces to the sample. The Evolution Powder Analyzer measures the unconfined yield strength by direct compression thereby applying no shear forces to the sample. The Revolution Powder Analyzer measure dynamic powder flow properties by causing powders to flow in a rotating drum. The shear forces in this case are created by weight of sample above the powder flow zone and thus are extremely low.

These measurements are in stark contrast to other flow measuring instruments like shear cells and powder rheometers. Shear cells by definition put a great deal of shear on test samples and this shear is concentrated on a shear plane in the sample where the measurements are made. Shear cells are generally used to design silos and hoppers where their results are used in specific formulas. They are not the best for studying and comparing powders.

Powder rheometers also put a great deal of shear force on test samples. In fact, some much shear force is put on the samples during rheometer measurements that so called “conditioning” procedures must be used to get stable results. These procedures basically put a high level of shear on test samples before measurement so trending in rheometer measurements are less apparent. Not mentioned is how this high shear changes the powder itself.

Flow Properties Tests.

Powder State	Instrument & Test	Test Type
Consolidated	Evolution Unconfined Yield Strength	Static Macro-Structure Instantaneous
	Evolution Time Consolidation	Static Macro-Structure Stability
Consolidated to Unconsolidated	Revolution Caking Test	Dynamic Micro-Structure Stability
Unconsolidated to Consolidated	Revolution Handlability Test	Dynamic Micro-Structure Stability
	Revolution Packing Test	Dynamic Macro-Structure Instantaneous
Unconsolidated	Revolution Flowability Test	Dynamic Micro-Structure Instantaneous
Unconsolidated to Fluidized	Revolution Multi-Flow Test	Dynamic Micro-Structure Instantaneous
Fluidized to Unconsolidated	Revolution Settling Test	Dynamic Micro-Structure Instantaneous
	Revolution Flow-Fluidization-Flow Test	Dynamic Micro-Structure Stability
Fluidized State	Revolution Fluidization Test	Dynamic Micro-Structure Instantaneous

Evolution Unconfined Yield Strength

Test Type: Instantaneous Static
Measures: Macro-Structure

The Evolution Unconfined Yield Strength Test is used to determine the force needed to break a mass of powder after being consolidated under pressure. This force is called the yield strength. For gravity flow applications, the force required to cause a powder or granular material to flow is created by the mass of the material itself. The material will flow if the force moving it (mass * gravity) is greater than the yield strength of the material. Typically the pressure used matches the pressure of the application. Several pressures can also be used to create a flow function, which is a consolidation pressure versus strength graph.

The Evolution Powder Analyzer uses uni-axial compression to assess the flowability of powders. The operator begins the flowability test by filling the analysis cell with either 25 cc or 75cc of sample. The cell is then placed in the Evolution and the material is compressed to a predefined pressure. This pressure is referred to as the major consolidation stress.

After compression, the Evolution removes the sample from the cell and applies force to the material until it breaks. The pressure required to break the sample is the unconfined yield strength. The unconfined yield strength represents the force required to make the material flow. A flow factor can be calculated by dividing the major consolidation strength by the unconfined yield strength. The greater the value of the flow factor the better the material will flow at any given pressure.

Flow Factor	Classification
< 1	Not flowing
1 < ff < 2	Very Cohesive
2 < ff < 4	Cohesive
4 < ff < 10	Easy Flowing
< 10	Free Flowing

Table 1

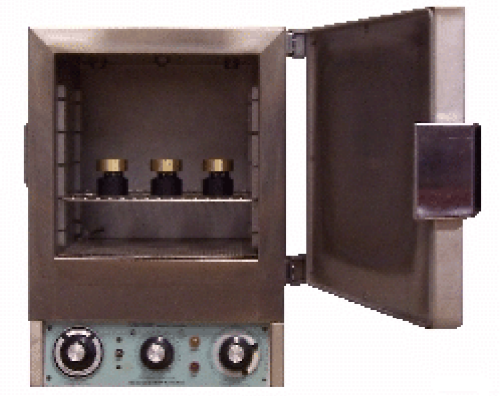
Table 1 presents generally accepted classification of powders and granular materials with different flow factors.

A plot of the unconfined yield strength versus the major consolidation stress is referred to as a flow function and represents the material's flowability under a wide range of pressures.

Evolution Time Unconfined Yield Strength

Test Type: Static
Measures: Stability of Macro-Structure

The Evolution Time Unconfined Yield Strength Test measures the unconfined yield strength of a sample after it has been consolidated under pressure for a specified time. The pressure is created by placing a weight on the lid of the test cell. Tests can be carried out a various temperatures and humidities to simulate real world storage conditions. Normally powders under pressure gain strength over time. This means that more force is required to break the bonds between particles and initiate flow.

	
Evolution Time Cell consolidation force maintained on powder over time using brass weight	**Time Cells In Oven** effects of temperature and pressure over time are easily studied

Revolution Dynamic Flowability Test

Test Type: Instantaneous Dynamic
Measures: Micro-Structure

The Revolution Powder Analyzer tests dynamic powder flowability by rotating sample powders very slowly in a test drum with borosilicate glass sides. The operator begins the flowability test by filling the rotating drum with 100 cc of powder. A motor rotates two high precision silicone rollers that in turn rotate the drum. A digital camera with the assistance of cold cathode back-light illumination takes digital images of the powder during the rotation process. From the images collected, the software measures the behavior of the powder due to the drum rotation and how this behavior changes over time.

The digital camera captures images of the powder in the rotating drum at the specified rotation speed. The three images displayed below represent an avalanche cycle from initial image, peak and the completed avalanche.

Building

Peak

Minimum

In every image collected, the software measures many aspects of the powder, including the potential energy, angle, surface fractal and volume. The Revolution Powder Analyzer calculates the avalanche energy by measuring the change in potential energy before and after the powder flows creating an avalanche. The powder builds up to a maximum (break energy) and then flows to a lower energy (rest energy). The avalanche energy is the difference between the Break Energy and Rest Energy. All three parameters can be interesting for characterizing powder behavior but the avalanche energy typically is what is most important. Avalanching is what makes a powder a powder as opposed to a liquid or solid. Also the standard deviation of these values are important.

In understanding powder flow in the Revolution Powder Analyzer (RPA), it is interesting to compare powders to liquids or solids. A non-viscous liquid like water in the RPA drum will stay across the bottom of the drum. Break Energy, Rest Energy and Avalanche Energy will be zero as the liquid does not move up the drum. Now consider a viscous liquid like oil. When the drum rotates it will move up the side of the drum but stay in one position. The break energy will be a value based on how far up the drum the liquid goes. However, as the powder flows continuously, the rest energy will be equal to the break energy making the avalanche energy zero. Now consider a solid block in the RPA drum. It will move up the drum then tip over. The break energy will be how high up the block goes before tipping over. The rest energy is where the block ends up at the bottom of the drum. All the energy in the block is released. So if we look at powders, their behavior is between liquids and solids. They do not flow continuously but also do not release all of their energy. Also the energy release can vary. So the best flowing powders have both a low avalanche energy and a low avalanche energy standard deviation.

The manner in which a powder flows in the RPA drum is effected by many factors, including powder micro-structure, particle size, particle density, particle shape, solid to gas ratio, particle surface properties, etc. In general terms, the larger the real or effective particle size of the powder, the better the powder will flow. The rounder the particles are in the powder the better the powder will flow. The lower the friction between the particles in the powder the better the powder will flow. Better flow means lower avalanche and break energies when tested with the RPA. Therefore by monitoring these values, the impact of changes in powder characteristics, whether planned or unplanned, on powder flow behavior can be studied.

Revolution Caking Test

Test Type: Dynamic
Measures: Stability of Micro-Structure

There are two types of caking in powders, macro-scale caking and micro-scale caking. Macro-scale caking involves joining of powder particles to form a unified mass of material. Micro-scale caking, also referred to clumping or agglomeration, is an increase in effective particle size of particles in a powder. The Revolution Powder Analyzer Caking Test measures micro-scale caking.

There are many mechanisms for caking in powders including cohesive bonding, van de waals force, surface dissolution, etc. It is typical to measure the macro-structure of a powder mass after exposure to pressure as in the unconfined yield locus test to predict micro-structure powder caking. However, these macro-structure tests are not good predictors of increases in effective particle size due to the development of micro-structure. The reason is twofold – 1) the forces involved in bonding particles

together are orders of magnitude lower than the forces involved in macro-structure experiments; 2) powder macro-structure breaks at its weakest points meaning much stronger bonds can be present even in powders with low strength macro-structure. Therefore it is necessary to measure powder micro-structure directly to control powder caking behavior.

The Revolution Powder Analyzer measures the caking behavior of powders in a three step process: 1) A sample of powder is measured using the RPA flowability test; 2) the sample is removed from the Revolution drum and placed in a compression cell and is compressed at a known pressure under known environmental conditions for a pre-determined time, and 3) after compression the sample is returned to the RPA sample drum and the flowability test is run again. Changes is powder micro-structure and effective particle size are measured by comparing sample data before and after compression. When caking occurs, typically the avalanche energy of the powder decreases while the dynamic density of the powder increases. The dynamic density is the density of the sample powder flowing in the RPA sample drum.

After the caking test, the RPA drum speed can be increased to cause the caked powder particles to smash again the side of the drum and each other to assess the strength of the bonds between the caked particles.

Revolution Handleability Test

Test Type: Dynamic
Measures: Stability of Micro-Structure

The Revolution Handleability Test measures how stable a powder is on handling. When powders flow or are moved, they are exposed to shear forces that cause powder particles to impact each other and their surroundings. Theses shear forces and impacts can have considerable effects on the particles making up the powder and how they interact. Granulation is an increase in the particle size of particles in a powder. Attrition is a break down in the size of particles in a powder. Other changes include embedding of flow agent into powder particles.

The test is at minimum a three step process: 1) A sample of powder is measured using the RPA flowability test; 2) the drum speed is increased and the sample is rotated in the sample drum for a fixed period of time to allow the sample particles to interact with each other, and 3) the RPA flowability test is run again. If granulation has occurred, the avalanche energy decreases and the dynamic density increases. If attrition has occurred, the avalanche energy increases and the dynamic density decreases. If embedding of flow agents has occurred, the avalanche energy increases and the dynamic density

increases.

Revolution Packing Test

Test Type: Instantaneous Dynamic
Measures: Macro-Structure Formation

The Revolution Packing Test measures a powder's ability to pack or settle after being exposed vibrational energy. The test measures the change in the powder density and the force required to break the powder mass and induce flow after exposure to vibrational forces.

When powders are exposed to vibrational forces, the particles of the powder flow around each other and fill in air spaces between the particles in a process known as packing. Many factors affect a powder's ability to pack including powder particle size distribution, particle shape, and how well the powder flows. Typically the better a powder flows the more the powder will pack. This increases the density of the powder. Once packed close together, the powder particles can then interact to form macro-structure. The Revolution measures this macro-structure by calculating the energy required to induce flow in the powder mass after packing.

The Revolution Packing Test has three process steps: Prep, Vibration and Analysis.

Sample powder is loaded into the test drum of the Revolution Powder tester and the drum is closed.

1) Prep - The Revolution rotates the powder at a chosen rotation rate and length of time to condition the sample material. This step will establishes a repeatable initial powder state before beginning the packing analysis. After the initial preparation, the digital camera captures several images of the powder to calculate the powder's volume after prep.

2) Vibration - The motor in the Revolution Powder Analyzer vibrates the powder for a period of time at a specified amplitude and frequency. After the vibration, the digital camera captures an image of the powder to calculate the powder's volume after vibration. The percentage change in volume from after prep and after vibration indicates the sample's ability to compact or pack during storage and transportation.

3) Analysis - After the volume measurement is collected, the powder is rotated at a specified speed until the compacted powder breaks (or avalanches). The software captures the angle when the powder breaks and the amount of drum rotation required to break the powder. After the powder breaks, the

software calculates the energy (or force) required to initiate flow in the sample. The volume is measured and calculated.

The digital camera captures images of the powder during the three process steps described above. The three images displayed below represent the powder samples after preparation, after vibration and prior to the powder break.

After Prep

After Vibration

Before Break

Revolution Multi-Flow Test

Test Type: Instantaneous Dynamic
Measures: Micro-Structure

Powders can behave very differently depending on the amount of energy they are subjected to as they move through handling equipment. One powder may flow more evenly as it is subjected to more mechanical energy while another powder may become erratic. This behavior can be studied using the Revolution Multi-Flow Test Method. In the multi-flow method, the sample drum speed is increased gradually over time and the sample powder's behavior is measured.

The Multi-Flow Analysis studies how a powder or granular material transitions from avalanching to continually flowing as it is subjected to faster speeds. By gradually increasing the rotation speed in the Multi-Flow Analysis, the user can evaluate the speed at which their powder is no longer avalanching in their process but flowing continuously. This data can be used to predict how powders will behave in high speed equipment.

Revolution Fluidization Test

Test Type: Instantaneous Dynamic
Measures: Micro-Structure

A powder is fluidized when a gas is injected into the powder causing the powder particles to separate and enter a fluid like state. In this fluidized state, powders behave more like liquids than powders. Powder fluidization can help or hurt the use of a powder. Some powder applications require a powder to fluidize for its use, such as powder coatings or toners. Fluidization can make it easier to transfer powders from one location to another. However, fluidization has a large downside for many applications. Powder handling equipment typically cannot control fluids. Therefore powder handling equipment cannot control powders that are fluidized and acting like fluids. Also, powder particles can easily segregate when the powder is in a fluidized state.

The properties of the powder, as well as the pressure and temperature of the gas, determine the degree of fluidization. For fine powders, the gas pressure required to fluidize the particles is very low. This low pressure can be created by rotating the powder in a drum. Varying the rate of drum rotation in the Revolution Powder Analyzer results in changes of the fluidization pressure.

The fluidization of a fine powder is studied by measuring the volumetric expansion of the powder in the rotating drum as a function of the rotation rate of the drum. After the powder has fluidized and the drum rotation has ended, the rate of decrease in the powder’s volume is measured to create a settling function for the material.

Revolution Settling Test

Test Type: Instantaneous Dynamic
Measures: Micro-Structure

Once a powder has fluidized, it will gradually return to the unconsolidated or consolidated state after the fluidization energy has stopped. This transition is refereed to as settling. The Revolution Settling Test measures the time it takes for a powder volume to stabilize as the powder settles after fluidization. Settling is very important for powder handling. For most applications, fluidization is not a problem as long as a powder settles quickly and returns to a unconsolidated or consolidated state. The reason is simple. Powder handling equipment cannot control fluids so the longer a powder is in a fluidized state, the more problems powder equipment will have controlling it.

Revolution Flow-Fluidization-Flow Test

Test Type: Dynamic Stability
Measures: Micro-Structure

Powders change state as they are moved through processing equipment. These state changes can be permanent or transient. The Revolution Flow-Fluidization-Flow Test measures how powders transition from the unconsolidated to fluidized state and then back to the unconsolidated state. This transition is important as powders are typically delivered to process equipment by vertical pipes and chutes where they are fluidized. They then move directly to processing equipment that must control the powder in a uniform and repeatable way. This is difficult if the powder flow properties are varying due to powder state transitions.

The Revolution Flow-Fluidization-Flow Test consists of three steps. First the powder's dynamic flowability is measured using the Revolution Dynamic Flowability Test. Then the powder sample is fluidized using the Revolution Fluidization Test. After fluidization the powder's dynamic flowability is again measured using the Revolution Dynamic Flowability Test. After testing, the powder's dynamic flowability data before and after fluidzation is compared. The most stable powders show little change in the before and after data.

Sampling and Repeatability

Powder flow tests can be more or less repeatable from powder to powder. The reason is due to the memory effects of powders. Powders that exhibit strong memory effects are generally more difficult to test repeatably. Typically these powders are cohesive and compressible. For these types of powders, steps must be taken to control memory effects. It must be understood, however, that these steps are controlling memory effects for the sake of testing and they may be removing the powder flow problem that actually needs to be quantified.

The following is a list of memory effects and how to reduce or control them:

1) Clumping, caking, and/or aggregation: Before testing, clumps, caked particles and agglomerates should be removed by chopping the powder with a flat edged knight, shaking the powder container, or by passing the powder through a screen. If the clumps or aggregates are natural to the powder they will return quickly with handling. If they are a result of

environmental conditions or storage pressures they will not return.

2) Aeration: Powders that are mixed or shakes too heavily may become aerated. These powders should sit for a time in a shallow container.
3) Segregation: Powders containing a wide range of particle sizes can separate on handling. These powders should be carefully mixed and then split by a sample splitter into appropriate test sizes.
4) Charge: Static charges can easily build up on powders causing their flow properties to change. Electrically unstable powders should either sit in a neutral environment or be deionized before testing.

When testing powders, it is always best to test powders before and after steps are taken to remove memory effects.