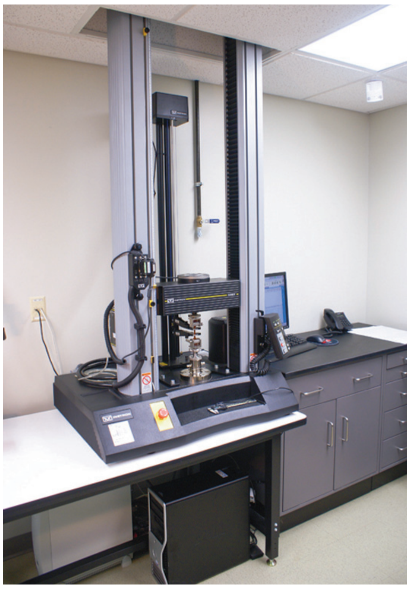
R. Todd Swinderman, P.E., and Andy Marti, Martin Engineering, US, discuss how bulk material science is improving power plant coal handling.

One of the greatest advancements in the engineering of coal handling systems is the increased use of bulk material science. This field is focused on the testing and analysis of both the bulk solid and the construction materials that the bulk solids will move on, over or through. Bulk material science is an interdisciplinary field, centred on determining the physical properties of bulk materials and applying those properties to various problems in the design of bulk material handling systems and components.

Combined with computer-based engineering and modelling systems, bulk materials science offers several potential improvements for coal handling operations in power plants. These include helping to manage flow, reduce bottlenecks, minimise dust, spillage and carryback, extend equipment life and reduce maintenance expenses – all improving a plant's availability, efficiency and profitability.

Since the first conveyor was designed, the basic properties of bulk materials, such as bulk density and angle of repose, have been used to size the system and calculate its power requirements. Modern bulk material science traces its roots to work at the University of Utah, which determined the critical dimensions of mass-flow bins, based on the strength of the bulk material under various conditions. These methods are used to determine the internal strength of bulk solids and the friction between them and the belt or chute. These properties are used to predict the behaviour and flow of the bulk solids from silos and storage vessels and, later – with increasing success – through chutes and onto belt conveyors.

CFI ring shear tester: the ring shear tester is used to measure the flow properties of powders and bulk solids.



This Instron provides the basis for a variety of physical property tests, including rigidity, tensile strength, and compression.

Improved testing and computerised engineering now make it possible to improve designs of specific systems to perform as expected with identified materials. Serious errors can be made if a material handling system is designed without determining the appropriate basic and advanced properties of the specific bulk material being stored, conveyed or otherwise handled.

Standards

Many basic properties and tests for bulk solids are outlined in the Conveyor Equipment Manufacturers Association (CEMA) Standard 550. The properties most often used (and sometimes misused) in the design of belt conveyor systems are:

Bulk density

The bulk density of a material is the weight per unit of volume (kg/m^3 or lb/ft^3), measured when the sample is in a compacted condition. This vibrated or settled density is used with the surcharge angle for determining the volume of material conveyed on the belt.

Loose bulk density

Loose bulk density is the weight per unit of volume measured when the sample is in a loose or non-compacted condition. The loose bulk density must always be used when designing the load zone chutes and the height and width of the skirtboards, or the chute may not be able to handle its specified design capacity due to the increased volume of the material.

Angle of repose

The angle of repose for bulk materials is the angle between a horizontal line and the sloping line from the top of a freely-formed pile of bulk material to the base of the pile. This angle of repose for a given material may vary, depending on how the pile is created, as well as the density, particle shape, size consistency and moisture content of the material.

Surcharge angle

The surcharge angle is the angle of the load cross section, measured by the inclination in degrees to the horizontal. The surcharge angle is useful in conveyor design for determining the profile of the load on the belt for various belt widths and trough angles to calculate the theoretical carrying capacity.

Lump or particle size

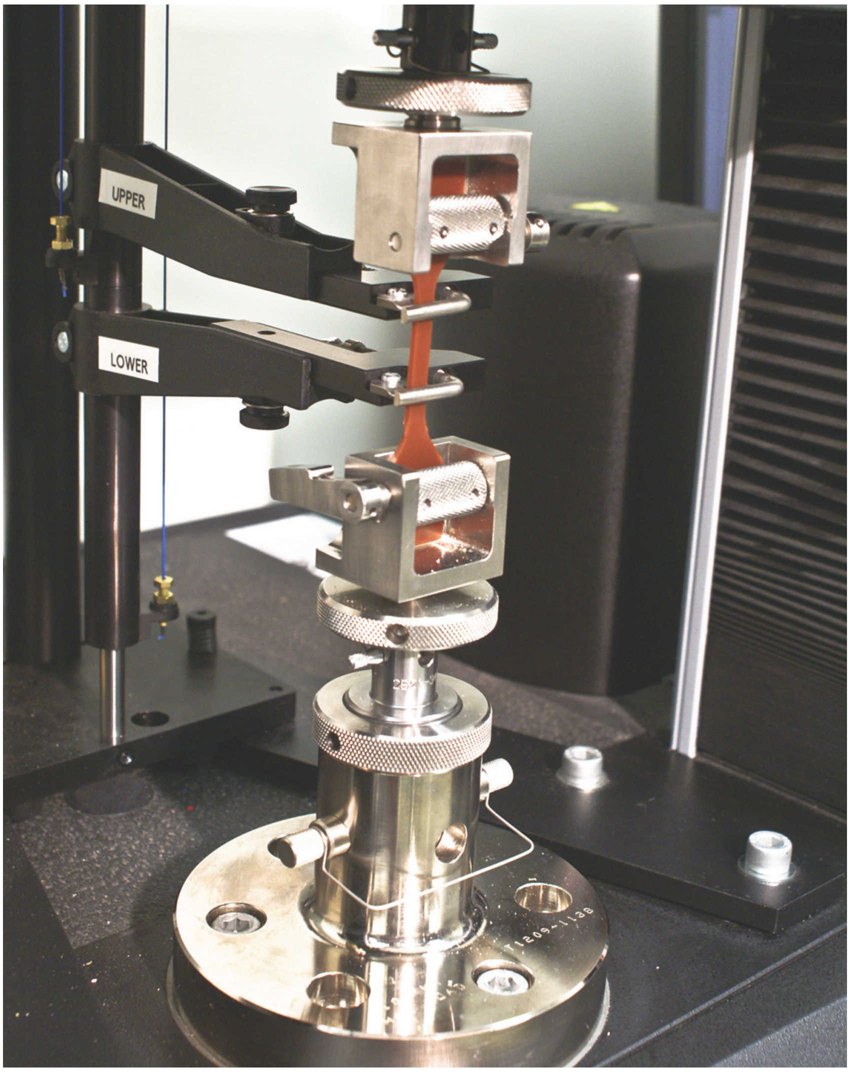
The size of a bulk material is described in two ways – as the maximum lump size, or as the percent of particles that will pass a series of standard screens (or sieves). Size is often listed as the maximum lump width and breadth. A material with a maximum lump width and breadth of 50 x 50 mm (2 x 2 in.) would be described as "50 mm minus" (or 2 in. minus) material. This means the largest lump is 50 x 50 mm and the rest of the particles are smaller. It is common practice to assume the length of the lump can be as much as three times larger than its width, or in the above example 150 mm (6 in.) long. This information is useful in sizing various components, as well as the width and height of chutes and skirtboards.

A screen analysis gives the most complete representation of the size of the bulk solid. The particle size distribution is a tabulation of the percent represented in each size range as part of the total sample, usually shown as passing a given screen size and being retained on the next smaller screen. This information is useful for analysing airflow in chutes and the potential for the creation of airborne dust.

Flow properties

The basic flow properties of a bulk solid can be derived from shearing the bulk solid (using a shear cell) and measuring the force required. Usually the fines from the bulk solid are tested, since they are the portion that changes strength with moisture and pressure and acts as the "glue" that retards flow.

The shear cell method is also used to measure the friction between the bulk solid and the belt or chute construction materials. For conveyors, the important conditions are the variation in strength with different moisture contents and consolidating



The tensile strength test is performed by stretching an "hour-glass" shaped specimen until it fails (breaks).

pressures. Shear cell tests are particularly time-consuming, because of the number of tests run at different moisture contents and consolidating pressures.

Interface friction

Two values of friction are important in chute design – the co-efficient of friction between the bulk solid and the chute wall, and between the bulk solid and the belt. Bulk solids, particularly the fines, have the ability to cling upside down on horizontal surfaces and exhibit strength, even under negative consolidating forces greater than gravity. The shear force of negative consolidating forces is of particular interest in chute design in determining adhesion and cohesion values.

Adhesion

Adhesion can be thought of as the stickiness of the material to surfaces, such as chutes and belts. Surface condition, moisture and impurities (such as clay) are the principle variables that affect the level of adhesive stress in a bulk solid. Adhesive stress can be determined from shear cell tests and is very useful in determining the likelihood of the material to stick or cling to surfaces.

Cohesion

Cohesion is the ability of the particles to stick to each other. Cohesion in a bulk solid is affected by three conditions: moisture content, electrostatic attraction and agglomeration (the tendency to lump together into a mass). Cohesive stress can be determined from shear cell tests and is very useful in determining how bulk solids will flow.

Applying test information

This empirical knowledge is certainly useful, but what are the implications for material handling systems and the design of equipment? What can material science help determine more accurately?

Conveyor capacity

Conveyor capacity (tph) is one of the basic design parameters directly calculated by knowing the density of the bulk material. Density refers to solids such as steel or concrete (particle density).

However, in conveyor design, there are several densities to consider that are typically fractions of the material's particle density. Settled bulk density is used with the cross-sectional area of the load on a belt to determine the nominal carrying capacity of the conveyor. Loose bulk density can be as little as half the settled bulk density. The settled bulk density is the state of the material as it is normally carried on the belt.

If a conveyor transfer point is designed using settled bulk density, it will likely plug at less than its rated capacity, because the material flowing from one belt to the other takes up more room. In this case, the plant is trying to get 10 lb of loose material through a space designed for 10 lb of condensed material.

If an inexperienced designer looks in a general engineering handbook for a material's density, the value listed will probably be the particle density. The particle density or true density of a particulate solid or powder, is the density of the particles that make up the powder, in contrast to the bulk density, which measures the average density of a large volume of the powder in a specific medium (usually air). Using the particle density, the inexperienced designer can oversize the conveyor by afactor of two to three. This error will have serious consequences in unecessary costs.

Chute design

Chute design is more than a matter of having the correct cross-sectional area based on the loose bulk density. The reliable flow of bulk solids through a chute depends, among other factors, upon the friction between the bulk solid and the chute walls and wear liners. If the friction is too great, the material will slow in its passage through the chute. This decreased flow leads to bottlenecks, buildups and blockages.

The design of the new generation of flow-engineered chutes depends on knowing the properties of the bulk solid in relation to the flow surfaces. Most often, when a handbook value of chute angle based on the angle of repose or surcharge is used, buildups leading to blockages are the result. For example, lignite has a significantly higher co-efficient of friction on stainless steel than bituminous coal, but the co-efficients of friction are similar when ultra-high molecular weight (UHMW) polyethylene is the liner. Serious flow problems can result from not testing the actual bulk material transported and the actual lining considered for the design.

The data from the testing of the specific coal being used and the specific construction materials, such as stainless steel or ceramic liners, is critical. It will help predict the flow of the material through the chutes, reduce wear on components, and eliminate the escape of fugitive material like spillage and airborne dust.

Belt cleaning

The properties of a bulk solid can only be used as a general guide to predict the nature of the belt cleaning challenge the operation will face. By testing the properties of the carryback, predictions can be made as to how much the fines will adhere to the belt past the discharge and how changes in conditions – such as an increase in moisture level from a rainstorm – can affect carryback levels and cleaning performance. The fines used for testing bulk solids are on the order of 2000 times larger than the average carryback particle. Carryback acts like a powder, where the physical properties are more related to surface tension and nuclear forces on a micro level than those of particles typically used for testing bulk solid flow. The stresses in bulk materials are mainly created by mechanical interlocking and surface moisture of larger particles on a macro level. Applying bulk solid properties to carryback can significantly underestimate the projected carryback levels and cleaning performance.

Adhesion and cohesion of carryback sized particles are important properties used in this prediction. Knowing the material's critical moisture content – where its adhesion and cohesion change dramatically – allows a designer to calculate the volume of water needed to reduce the carryback material's strength or to wash the belt.

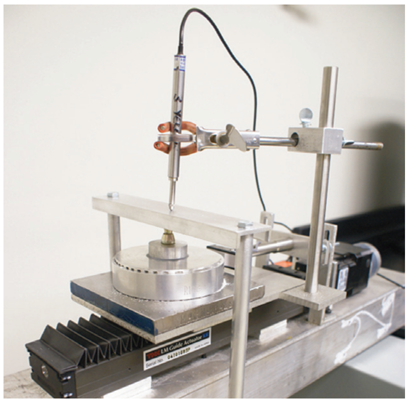
Safety

Testing a bulk solid for its properties allows the designer to develop safe storage and conveyance for bulk solids. For example, flowing bulk solids can create unequal wall pressures on silos. Without testing the specific materials under the expected conditions for storage and haulage, a designer is only guessing at the forces involved. There have been many instances in which a worker has been injured by falling material when trying to remove buildups from a chute. Less catastrophic, but just as damaging to productivity, are systems designed using typical or average values to design conveyors. Many a conveyor designed without the specific knowledge of the material properties has failed to deliver its design capacity.

The benefit – or consequence – of material testing: an example

The numerous varieties of coal can have very different characteristics. The CEMA 550-2003 publication *Classification and Definitions of Bulk Materials* lists nine different classifications for coal, from 0.5 in. minus anthracite to ROM bituminous. This reference lists from 45 – 60 lb/ft^3 as the loose bulk densities for various coals, with surcharge angles listed from 20 – 30˚.

At Martin Engineering's Center for Innovation, the process simulation area incorporates a three-belt recirculating conveyor loop for observation of material flow and component life.



The direct shear tester determines a material's friction, cohesion and adhesion to a substrate such as a liner material.

A dry abrasion tester checks three-body abrasive wear, as between a conveyor belt, a metal chute liner and the bulk material.

The 6th edition of CEMA's *Belt Conveyors for Bulk Materials* gives detailed equations for calculating the capacity of a conveyor based on the trough angle and the surcharge angle. To demonstrate the value of basic material data, the cross sectional areas found by using the values of two different coals from either end of the published list can be compared.

Givens

- Loose bulk density: 45 – 60 lb/ft^3 (720 – 960 kg/m^3).
- Angle of repose: 30 – 40°.
- Angle of surcharge: 20 – 30°.
- Belt width: 48 in. (1200 mm).
- Trough angle: 35°.
- Edge distance: standard CEMA edge distance.
- Belt speed: 500 fpm (2.5 m/s).

The publication specifies the cross-sectional areas:

- 20° surcharge angle: 1.804 ft^2 (0.168 m^3).
- 30° surcharge angle: 2.100 ft^2 (0.195 m^3).

Therefore, the range of the quantity of material/ft of the conveyor is:

- Cross sectional area x loose bulk density/ft^3 x ft of belt

In this example, there is a range of 81.2 – 126 lb/ft (1.804 ft^2 x 45 lb/ft^3 x 1 ft to 2.1 ft^2 x 60 lb/ft^3 x 1 ft).

The quantity of material conveyed at 500 ft/minute then ranges from 1218 – 1890 tph (81.2 lb/ft x 500 ft/minute x 60 min/hr/2000 lb/t to 126 lb/ft x 500 ft/minute x 60 min/hr/2000 lb/t).

Summary of example

The differences in loose bulk density and surcharge angle yield a shortfall in conveyor capacity of more than 600 tph. This error would have a major effect on the ability of the coal handling system to achieve its production rate, and therefore hinder the ability of the entire plant to achieve its operational goals. If this plant relies on 1800 tph to fill its day bins or coal bunkers and only gets 1200 tph through the system, the plant will need to operate its conveyors on a longer schedule, increasing hours for both personnel and equipment, or downrate its generating capacity.

What it all means

No two bulk materials are the same, no matter what type or classification they are. This is the main reason why physical testing of a bulk solid is so important to proper design of bulk material handling systems. The cost of testing is a minor part of the overall cost of a material handling or conveying system. Having this data is one of the most important tools for trouble-shooting the conveyor in the future, when processes or raw materials change.

If an existing material handling system works now, it should continue to work as long as the material stays the same and the equipment does not suffer wear or abuse that changes its performance. But changes in material – from changes in source or increased moisture from rain, or from changes in the process or in the equipment, like increasing the speed of the belts to move more material or changing a liner inside a chute – can have dramatic consequences on the performance of a coal handling system.

And when a material handling system is being engineered, whether designed from the ground up, or substantially rebuilt, then the materials it will carry need to be carefully tested to achieve the overall performance required and receive the maximum return on investment.