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Development of new analysis methods for the characterization and classification of wet sticky ores

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ABSTRACT

Economic drives dictate the exploitation of formerly less attractive ore bodies located close to or even beneath the water table. These ores can cause handling problems and expensive downtime of processing equipment due to their increased adhesive characteristics and are colloquially termed as “wet and sticky” ores.

In order to gain a better understanding of the causes of poor performance in the handling process, experimental test methods for adhesion and cohesion within bulk solids samples were developed and validated. The results confirmed that adhesion of bulk solid to equipment surfaces is mainly governed by capillary pressure. It can therefore be described using the Young–Laplace equation, which implies that adhesion is primarily dependent on the interfacial water between bulk material and the adhesion partner. Accordingly, the governing material parameters of adhesion are its capillarity and permeability, as these two characterize water transport to or from the interface of the adhesion partners. Furthermore a threshold for the classification of a material as wet and sticky based on the measurements of adhesion and cohesion has been proposed.

1. Introduction

Equipment used in bulk solids handling includes silos, hoppers, transfer chutes and feeders. In order to keep the running costs of this equipment low and to obtain maximum yield from investments, it is necessary to ensure a high degree of reliability regarding the continuous operation.

The ongoing exploitation and subsequent decrease of favourable ore bodies (in view of handleability) dictate the turn of mine sites towards formerly less attractive deposits. A multitude of these ore bodies are located close to or even beneath the water table and can cause handling issues due to their enhanced adhesive and cohesive characteristics. These materials can increase wear and cause expensive downtime by clogging up processing equipment. Especially transfer chutes, hoppers and screens are prone to clogging. The high propensity of material adhesion is also leading to increased carry back on belt conveyors.

The additional handling costs caused by downtime and sub-optimal running conditions for wet and sticky ores (WSO) range between 4 and 6 AUD per tonne [6]. This leads to a significant financial impact on the mineral industry. The underlying causes of WSO behaviour are still poorly understood and there is a lack of methods to predict their impact on mining operations. In order to gain a better understanding of the characteristics of these ores, to find a method of their classification, and ultimately to find ways of overcoming WSO handling issues, test methods for adhesion and cohesion within bulk material were developed.

2. Relevant mechanisms for handling problems

Macroscopic adhesion only occurs when a material is adhesive enough to adhere to equipment surfaces as well as cohesive enough to adhere to the first layers of material adhering to equipment surfaces [3]. It is therefore necessary to consider both mechanisms, when investigating issues of clogging and build-up.

Adhesion is generally defined as the attraction forces between molecules of different matters. It can occur between solids, between solids and liquids or between gases and either of the formerly mentioned [5]. In bulk material handling the adherence of bulk materials to handling equipment surfaces can be regarded as adhesion. Cohesion on the other hand is defined as the internal force of similar material adhering to itself. In bulk solids handling cohesion is defined as the bulk material adhering to itself. Bulk materials typically consist of a number of different minerals and organic substances, leaving this definition physically inaccurate. For bulk solid handling, however, this definition is advantageous.

The cohesive and adhesive forces can be categorised further by the direction of the applied forces, as shown in Fig. 1. In a wall friction test, there are adhesive shear forces acting on the sample (in addition to the friction forces caused by the normal load). When a sample is pulled off a wall surface in vertical direction, the forces acting can be described as adhesive tensile forces. The same differentiation can be made for cohesive forces. An internal shear failure, as occurring during the

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Nomenclature

d_2	diameter of adhesion interface [m]
A	area of adhesion interface [m^2]
F_{a0}	adhesive tensile force [N]
F_C	Capillary force [N]
F_{c0}	cohesive tensile force [N]
r_1	radius [m]
S_{a0}	adhesive shear force [N]
γ	surface tension [N/s^2]
σ_{a0}	adhesive tensile stress [Pa]
σ_{c0}	cohesive tensile force [Pa]
τ_{a0}	adhesive shear stress [Pa]

Jenike shear test, has to overcome cohesive shear forces (next to the internal friction forces induced by the normal load). A sample's internal failure with the failure plane oriented perpendicular to the induced forces has to overcome cohesive tensile forces.

The mechanisms relevant for build-up on handling surfaces are adhesive tensile force, adhesive shear force and cohesive tensile force. Experimental determinations of these properties will allow the characterization of investigated samples as problematic or unproblematic regarding issues of build-up. Furthermore, these measurements allow drawing conclusions about the physical mechanisms underlying adhesion of bulk material to surfaces.

Habenicht [4], showed that by solving the Young–Laplace equation for the capillary pressure between two steel surfaces connected by a liquid film as illustrated in Fig. 2, it is admissible to substitute the meniscus radius of the capillary liquid r2 with half the distance of the adhesions partners of 0.5 ∗ d2 leading to a simplified form for the adhesion force between the surfaces in form of

$$F_C = \gamma * \left(\frac{1}{r_1} + \frac{2}{d_2}\right) * \pi {r_1}^2, \tag{1}$$

where F_c is the force resulting from the capillary pressure, γ is the surface tension of the liquid and r_1 is the radius of the steel surfaces.

In this case, the capillary force is only dependent on the thickness of the liquid film between the adhesion partners. The theoretical adhesive tensile stress as a function of the thickness of the liquid bridge is shown in Fig. 3.

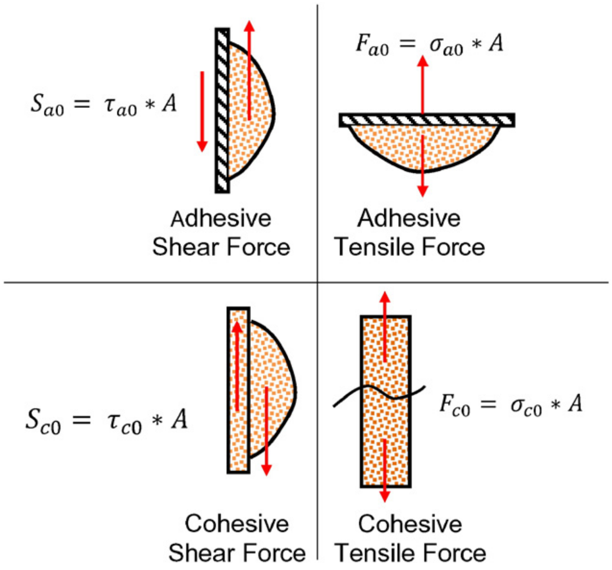

Fig. 1. Cohesion and adhesion of bulk material categorised by the acting forces relative to the resulting plane of failure.

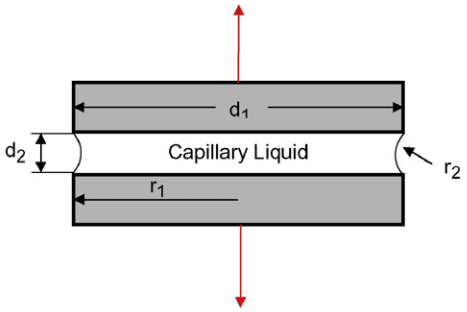

Fig. 2. Capillary model for solid surfaces.

Burbaum [3] determined the adhesive tensile stress between two stainless steel surfaces experimentally and validated Habenicht's theory. He was able to apply this model to a similar adhesion test between clay samples and stainless steel surfaces. Comparing simultaneous measurements of the adhesive tensile forces and the thickness of the liquid bridge on the interface with the mathematical predictions from Eq. (1) he was able to prove that for this case the capillary forces are the main source of adhesion.

3. Testers

In order to measure the bulk material properties identified as significant for problematic handleability in Section 2, three new testers were developed that are described in the following sections.

3.1. Adhesive tensile tester

With the adhesive tensile tester the tensile force required to pull off a bulk solid sample from a material surface in vertical direction can be measured. Adhesive tensile stress can be defined as

$$\sigma_{a0} = \frac{F_{a0}}{A}, \tag{2}$$

where F_{a0} is the force needed to separate the bulk material from the surface and A is the contact area of the adhesion partners.

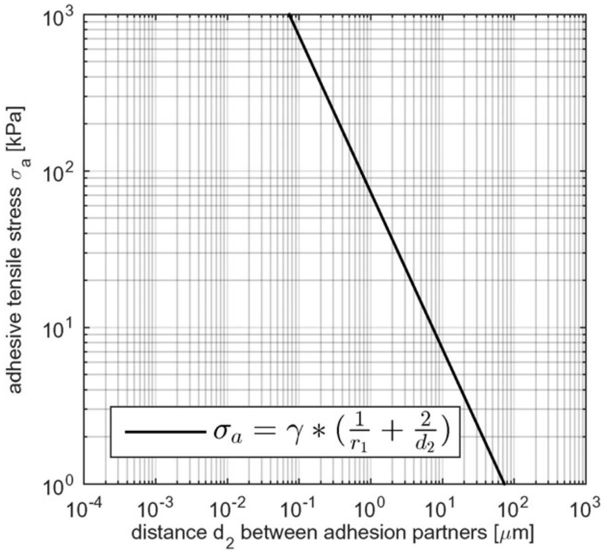

Fig. 3. Theoretical adhesive tensile stress derived from Eq. (1).