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The importance of wall friction between particulate solids and elastomeric belt

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ABSTRACT

A new experimental methodology is described for the combined measurements of both the static and the kinetic friction between a bulk solid and a conveyor belt. This area of investigation has all too often been neglected. The method of testing is based on a very well known principle of the operation of an inclined plane. The tester was designed while keeping in mind that tribological phenomena are influenced by various factors; these factors should be varied widely and independently, yet they should also be measured easily. In this preliminary testing using two coals and two rubber belts, several different operational conditions were used, such as load and moisture content. The experimental results confirm that both static and kinetic angles of friction between the belt surfaces and the coals tested are considerably higher than the presently recommended maximum inclination angle for belt conveyors. No two bulk materials are the same, and this is the reason why physical testing of a granular solid is so important to the proper design of conveying systems.

1. Introduction

The modern and future trend in surface and underground mining is to eliminate or combine functions and to increase continuity. In coal or soft ores, continuous miners or longwall shearers break and excavate mechanically and thus eliminate drilling and blasting. The continuity in transportation is also advantageous [1]. As a consequence, the cyclic haulage and hoisting methods and equipment, such as truck (trailer), rail (train), and skip (cage) will receive increasing competition in the future from the belt conveyor. Conventional troughed belt conveyors, thanks to such advantages as low operating cost, good gradeability, high output, and proven reliability are already the most widely used continuous haulage machines [1–3]. Their usage in in-plant movement of materials, long distance overland, and underground transportation is now widely established. Economic evaluations highlight the advantages of employing a speed greater than 6 m/s [2,4]. The trend towards higher operating speed on inclined belt conveyors emphasises the importance of the interaction between the bulk solid and the belt during conveying, feeding, and discharge [4,5]. The frictional interaction between the bulk solid and the belt is critical for the stability of the bulk solid on the conveyor belt during motion under various loading conditions and along a combination of horizontal and vertical curves, particularly, during starting and stopping of the conveyor [4,5]. The bulk solid is subjected to horizontal acceleration as the result of the belt movement between the idlers (providing that the belt sag, $y_{max} > 0$) [5], which induces the reduction of both the normal interaction and surface friction between the bulk solid and the belt leading to slip during inclined conveying. If the belt speed is fast enough, then lift-off and fall-back may occur. Both slip and lift-off can increase spillage.

An area that has been all too often neglected concerns testing the external coefficient of friction (wall friction) between the bulk solid and the belt in various tribological conditions. The testing should cover variables presented in Table 1.

Belt conveyors are frequently operated on an upward and a downward incline. The angles of maximum inclination are recommended on the basis of wide previous experiences and vary for coal from 15° to 20° [6–8]. The recommended angles are far below the actual values of the angles of friction between belt surface and the conveyed bulk solid. The angle recommendation is rather conservative, and its procedure is lacking in well documented experimental results from tribological investigations on the coefficient of static and kinetic friction between the specific bulk solid (e.g. coal with described essential characteristic — one coal is not all coal) and the carrying surface (e.g. rubber belt with essential material and surface characteristics). There were two objectives of this work: firstly, to develop a method of testing based on the very well-known principle of operation of the inclined plane, and, secondly, to supplement results published so far [7–10] using the method and apparatus.

2. Bulk solid and conveyor belt interaction

Fig. 1 illustrates the typical belt and material sag, in the vertical plane, that occur between idlers. The belt and material are lifted and bent in a convex shape at the idler and lowered and bent in a concave shape between idlers.

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Table 1
Three groups of characteristics effecting friction and adhesion between bulk solid and belt surface.

1	2	3
Bulk solid characteristics [2,4,5,9]	Wall surface characteristics [7,8]	Loading and environmental characteristics [3,4,7,8,17–19,26]
Particle size and shape	Surface roughness	Normal pressure
Particle strength	Chemical composition	Sliding velocity
Moisture content	Hardness	Temperature
Particle and bulk density	Modulus of elasticity	Humidity
Chemical composition	Rheological properties	Wall vibrations

The belt and material also undergo a continuous reshaping of the cross-section as they move from one idler to the next [11,12]. Fig. 2 illustrates this effect. At the troughing idler, Section A–A, the belt and material conform to the troughing idler shape. However, halfway between the idlers, at Section B–B, the belt and material have not only deflected downward but the sides have been flattened out (Figs. 1 and 2).

The continuous flexing of the belt and material in the vertical plane and the reshaping of the belt and material between idlers significantly affects the interaction between the belt and material and finally make a difference to material stability on the inclined belt conveyors.

When a bulk solid is transported on a belt conveyor, flexure resistance occurs between successive idler sets as the bulk solid undergoes transverse and longitudinal displacement due to the sag of the belt. Flexure resistance occurs due to the internal friction of the bulk solid and friction at the belt and bulk solid interface [11]. Experimental testing on the internal and external friction enables theoretical approximations for the transverse and longitudinal components of the flexure resistance and subsequently energy saving by optimal troughing idler design [1,2].

As it was already pointed out, when the belt moves between the idlers, the bulk solid is subjected to transverse acceleration in the "y" direction (Fig. 4). This acceleration can result in reduced interaction between the bulk solid and the belt and reduced the surface friction junction between them leading to slip, which impedes inclined conveying [4]. If the belt speed is high enough, then lift-off and fall-back may occur. Both slip and lift-off can give rise to spillage and limit the maximum inclination angle of belt conveying. All these detrimental phenomena are partly dependent on value of coefficient of friction between the belt and the bulk material as presented in several equations by Roberts [4,5].

In order to provide a greater insight into the mechanism of slip and fall-back, forces acting on bulk solid mass element in contact with belt are shown in Figs. 5 and 6.

Referring to Figs. 1, 5 and 6, the following variables are defined:

X	idler spacing [m]
x	coordinate defining a location point on the belt [m] (Fig. 5)
θ	conveyor slope angle (inclination angle) [°]
v	dx / dt — belt velocity [m/s] (Figs. 1 and 5)
y_{max}	maximum belt sag [m] (Figs. 1 and 2)
y	belt deflection at location x [m]
Δm	mass of element (Fig. 6)
X_s	section of belt over which slip may occur (Fig. 5).

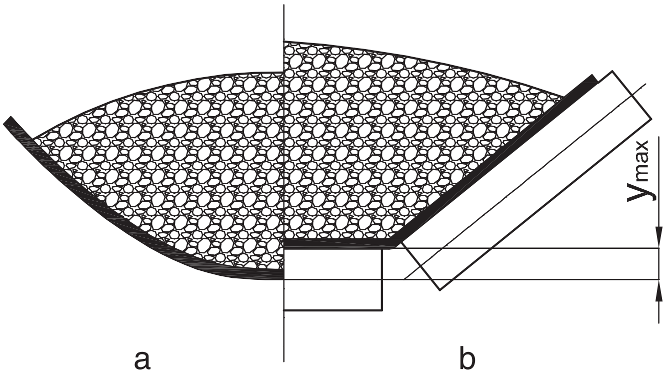

Fig. 2. Typical belt and bulk solid re-shaping, where: a) half section B–B and b) half section A–A (Fig. 1).

Considering a bulk solid mass segment at location "x", the forces acting are illustrated in Fig. 6. The variables shown are:

Δmg	weight of element [N]
N	normal force between the mass and the belt surface [N]
F_R	drag force [N]
F_A	adhesive force between bulk solid and belt [N]
$\ddot{y}$	transverse acceleration of belt [m]
$\Delta m\ddot{y}$	inertia force due to acceleration $\ddot{y}$ [N]
$\ddot{x}_r$	relative acceleration of mass when slip occurs [m/s^2]
$\Delta m\ddot{x}_r$	inertia force due to relative acceleration $\ddot{x}_r$ [N].

The forces in the transverse and longitudinal directions are given by:

$$N = \Delta m \cdot \left(g \cdot \cos\theta + \ddot{y} + \frac{F_A}{\Delta m} \right) \tag{1}$$

$$F_R = \Delta m \cdot (g \cdot \sin\theta - \ddot{x}_r). \tag{2}$$

The adhesive force F_A is given by

$$F_A = \sigma_0 \cdot \Delta A = \Delta m \cdot \frac{\sigma_0}{\rho \cdot h} \tag{3}$$

where:

σ_0	adhesive stress between the bulk solid and the belt surface [Pa] (Fig. 3)
ρ	bulk density [kg/m^3] (Fig. 3)
h	mean height of bulk solid on belt [m] (Figs. 3 and 6).

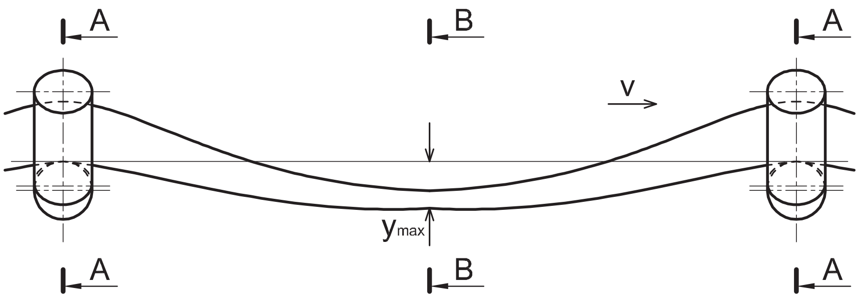

Fig. 1. Typical belt sag in vertical plane.