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Lithotype-based modelling and simulations of coal degradation conditioned by both high and low energy breakage

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ABSTRACT

The control of coal fragmentation and fines generation during mining and processing is important in coal production. A method to characterise, model and simulate coal size degradation and fines generation based on lithotypes has been developed. This method was refined to cover both high energy single impact to mimic blasting and crushing and low energy incremental breakage to mimic coal handling, transiting, stockpiling and processing. The JKRBT was utilised to characterise high energy single impact breakage and drop shatter tests were used to characterise low energy incremental breakage. X-ray Computed Tomography (XCT) scanning was used as an undisruptive technique to estimate size distributions of drill cores in the drop shatter tests. The JK size-dependent breakage model was applied for breakage characterisation, size degradation modelling and fines generation simulation. The results indicate that coal lithotype has a significant influence on coal degradation and fines generation. This paper has demonstrated that the adaption of two distinct breakage characterisation tests and linkage via the one model is a significant advance in quantifying coal degradation and fines generation during coal production.

1. Introduction

Coal size degradation and fine coal generation can result in higher production costs and the reduced recovery in saleable coal during preparation. Size degradation of coal occurs in blasting and crushing processes where high energy single impact is applied. This mode of breakage may generate coal fines as well. Size degradation of coal may also occur during the material handling that takes place during transport from mine to plant and from plant to port. During this process, coal is continually subjected to low energy repetitive breakage as it is loaded into rail cars, transferred to and from dump trucks, transported along belt conveyors, during shipping, during dozer rehandling and via weathering on a stockpile. For effective plant design and coal mine operation it is important to characterise coal size degradation and in particular the generation of fines, which in this paper is referred to as the −0.5 mm particles.

Attempts to characterise coal size degradation and fines generation have been reported in the literature. Drop shatter test is one of the standard coal characterisation methods. In the ASTM Standard [1], 23 kg of coal sample is placed in a 457 mm (W) × 381 mm (D) × 711 mm (H) metal box. The coal sample used for the drop shatter test can be a single size (50–75 mm), or mixed sizes, or slack coals. The box is raised and the coal is dropped from a height of 1.83 m to land onto a steel plate. All the coal on the plate is returned to the box and again dropped. The coal after the second drop is screened using a set of standard sieves. The product size distribution (% retained) and the mean sieve size of each size fraction are calculated. The sum of a product of the percentage retained and the mean sieve size is determined for the feed (designated as “S”) and the dropped product (“s”) respectively in the case of mixed sizes or slack coal feed being used. The ratio of the sum of the product after dropping to that before dropping (s/S) is defined as the size stability (%), and (100 – size stability) is the friability (%). The drop shatter test is a simple way to characterise coal resistance to breakage subjected to low energy incremental impacts, and the single parameter, size stability or friability, is easily comparable for different coals tested with the standard method. However, the major limitation is that since the single parameter is not linked with energy input and the feed size, it is difficult to develop a relationship for simulations of coal degradation and fines generation using the size stability or friability parameter.

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Ayat and Hassani [2] used a "stiff testing machine" that is a Piston-Die compression testing device to treat 100 g of coal samples in the 2.36–3.35 mm size fraction. After the compression test, the coal sample was sized, and the amount passing 2.36 mm was defined as the degree of degradation. They found that the degrees of degradation had a good correlation with ash contents, moisture contents and carbon contents of the four coal samples tested. It is doubtful, however, if the differences in the measured degrees of degradation (72.40, 70.45, 70.43 and 66.60) are significant without presenting statistical errors in the experiment, and if the correlation of such data with coal properties is meaningful. Mikhail and Patching [3] used tumbling tests combined with scanning electron microscopy of coal micro-structure to investigate the degradation of friable Western Canadian coals. Esterle et al. [4] used a drop shatter test for different drill cores and found that dull coal that was massive and strong required more energy to break relative to brighter, more friable coals. An empirical description of parent size (band thickness) and daughter size after breakage was presented. In developing a model for a hammer mill, Shi et al. [5] used different maps of breakage characteristic matrices for individual lithotypes determined by a drop weight tester. It was demonstrated that by incorporating the lithotype-specific breakage distribution functions, the model could give accurate predictions of the hammer mill product.

Comparing to the relatively scarce references on coal breakage characterisation, the literature contains abundant references of ore breakage characterisation and modelling for the mining industry, which may be applied for the coal industry. Breakage testing devices such as the drop weight tester [6], SMC tests [7], Split-Hopkinson bar [8], Ultrafast load cell [9], Short Impact Load Cell [10] and JK Rotary Breakage Tester (JKRBT) [11]. In the low energy incremental breakage study, Krogh [12] reported that anorthosite particles become increasingly weaker after receiving multiple impacts. A similar trend was reported by Pauw and Maré [13] who found that after repeated impacts at a very low energy level, quartzite particles were eventually broken, some of them taking up to 80 impacts. Tavares and King [14] reasoned that particle weakening from repeated impacts is the result of the growth of crack-like damage. It has been reported that the breakage characteristic parameters are affected by the process of selection and classification of particles in the incremental breakage tests, which is breakage environment-dependent, and should be taken into account in the breakage characterisation process [15].

For coal breakage characterisation, modelling and simulation, it is desirable to develop mathematical expressions of coal degradation in relation to single impact high energy input and repetitive low energy breakage. Again, the literature shows that the similar research has been conducted for the mining industry. In developing mathematical models for ore breakage characterisation, Narayanan and Whiten [16] use a relationship between a breakage index (t_{10}) and specific energy (E_{cs}) and establish the t-family curves to determine the product size distribution. Tavares and King [14] develop a mechanistic model to describe particle breakage probability in relation to repetitive impact energy. Vogel and Peukert [17] present a breakage probability model based on a generalised dimensional analysis approach proposed by Rumpf [18] and a mechanical fracture model proposed by Weibull statistics [19]. Shi and Kojovic [20] modify the Vogel and Peukert's breakage probability model to describe the breakage index (t_{10}), incorporating a particle size effect in the model (the JK size-dependent breakage model). This work has been utilised to model low energy incremental breakage [21–23]. Twenty (20) applications of the JK size-dependent breakage model over the past 10 years since its initial publication has been reviewed [24–26]. Recently, work to re-define t-family relationship that was initially developed by Narayanan and Whiten [16] has been reported [27,28].

The ore breakage characterisation methods and models developed for the mining industry can be applied in the coal industry. This paper presents an example of using the JK size-dependent breakage model to characterise coal degradation conditioned by either high or low energy breakage for various lithotypes of drill cores, and use the calibrated lithotype-based models to simulate coal fine generations in a typical coal crushing and stockpiling operation.

Table 1
The drill cores selected for breakage characterisation tests.

Test	Core ID	Lithotype	Lithotype definition [29]
Drop shatter	128	C2 + C6	C1: > 90% bright bands;
	040	C3 + C5	C2: 60–90% bright bands;
	014	C6	C3: 40–60% bright bands;
JKRBT	137, 138, 139, 140, 141	C2	C4: 10–40% bright bands;
	82, 83, 84, 85, 86	C4 + C5	C5: 1–10% bright bands;
	80, 90, 91, 109, 111	C6	C6: < 1% bright bands;

2. Experimental details

2.1. Material

Drill core samples were selected from a Permian age coal seam, the Chipanga seam, in the Moatize Basin, Mozambique. The coal seam is 30 m thick in places and can be separated into a series of plies with different lithotype compositions and stone parting distributions. Cores selected were 80 mm in diameter and 150 mm–400 mm long. Lithotypes selected include C2, C3, C4, C5, C6, carbonate cemented stone and mixtures of these. The lithotypes designation follows the Australian Standard AS 2916-2007 [29], which is given in Table 1.

Core samples from two drill holes were selected based on visual logging performed to classify lithotypes and then checked using a hyperspectral technique [30]. Three drill cores from one hole were used for low energy incremental breakage tests presented in this paper, and 15 cores from the other hole were used for high energy single impact tests. Lithotype selection of the cores used in the high energy impact tests was firstly based on the geological logging data and then confirmed with X-ray Computed Tomography (XCT) scanning [31] to capture the texture and proportion of bright bands, and to check their densities in relation to lithotype. Five cores were selected for each of the three lithotype groups, with over 13 kg of core in each group for the high energy impact tests. The cores selected for the experimental work are listed in Table 1, together with the Australian standard lithotypes designation.

2.2. Breakage characterisation tests

Coal size degradation and fines generation occur by two major breakage mechanisms, high energy single impact breakage and low energy incremental breakage. Previous investigations published in the literature have the limitation that they often only focus on a single breakage mechanism. To overcome this limitation, two types of breakage characterisation tests were designed and conducted on different lithotypes of drill cores respectively in this study to acquire a complete characterisation data set for coal size degradation modelling.

2.2.1. High energy single impact breakage

A breakage characterisation device, the JKRBT [11] (Fig. 1), was used to perform high energy single impact breakage characterisation tests. The JKRBT uses a rotor-stator impacting system, in which core particles gain a controlled kinetic energy while they are spun in the rotor and are then ejected and impacted against the stator, causing particle breakage. The impact energy can be accurately determined from the rotational speed of the rotor that has been calibrated with a high speed video camera.

Drill cores were classified into three groups: Bright banded (C2), Banded (C4 + C5) and Stone (C6). Five cores were selected from each group (Table 1). To provide sufficient number of coarse particles in the 37.5–45 mm size fraction for the JKRBT tests, the selected cores were