The effect of the mode and top size of applied breakage on coal yield

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Abstract

Understanding the effect of the different types of breakage applied to coal can potentially increase coal yield while limiting excessive fines generation. The increased yield will be due to enhanced release of high value components such as coking macerals at finer crushing sizes. Combinations of breakage types (impact, compression, attrition) were studied after crushing to two top sizes; 6.7 mm and 13.2 mm. The optimum result was found using impact breakage to 6.7 mm followed by mild attrition for 1 minute to give an absolute coal yield increase of 36 % for a product of relative density 1.54 and an ash yield of 10 %.

Keywords: Coal; Liberation; Compressive breakage; Impact breakage; Attrition

1. Introduction

Some coal resources, like the Waterberg, Limpopo or Mozambique fields, have a highly interlayered morphological structure consisting of different coal maceral groups along with the discrete mineral structures, like mudstone layers. The latter is incombustible, and becomes altered during combustion remaining as an undesirable ash by-product. It therefore lowers the economic value [2, 6, 8] by reducing the calorific (heating) value of the coal [3, 6]. The term "ash yield" is related to the mineral matter occurring originally in the coal before combustion [5]. Some of the coal components have properties adding to the value of the product, like coking properties. It is therefore of economic importance to maximize the amount of valuable coal recovered from raw coal [3]. This coal can be of a low overall grade requiring beneficiation [2, 8], but even this may not improve the grade, because of the narrow layers.

Crushing to a size larger than that of the morphological features will simply reduce the size without liberating the individual constituents, and the particles will have similar densities than the uncrushed ones - all in the near dense range, thus lowering the economic value of the coal. There are some notorious examples of failed coal processing plants experiencing much lower yields than predicted because of this reason. Because of the morphological structure, yields can potentially be improved by crushing to a smaller top size and liberating the different coal quality fractions [2, 3, 8]. This would enable the separation of the undesirable incombustible or low value material from the valuable coal [2, 6, 8] to produce a low ash coal product [3]. On the other hand, fines production must be limited since handling and dewatering of fines are difficult and costly [3]. Despite these difficulties in fine coal processing, crushing of certain coal sources to smaller particle sizes prior to processing may be required to attain higher degrees of liberation to increase the plant yield by liberation of values from the middlings [3]. Middlings are defined as partially liberated coal fractions which still contain mineral matter after size reduction [1]. Thus, a clear understanding of breakage mechanisms during liberation will be required for a balance between sufficient liberation of coal to attain a certain yield, and the generation of excessive fines. Comminution (size reduction) processes must therefore be controlled, and optimized, to ensure that adequate liberation takes place, but also that the particle sizes are suitable for utilization [8].

Crushing and comminution processes are generally expensive, both in terms of capital expenditure and operational costs, and therefore an appropriate circuit is required to achieve the best liberation size to allow for maximization of the plant yield. If well designed, the production of fines can be minimized.

This study was done to determine some combination of breakage mechanisms, either compression breakage followed by attrition or impact breakage followed by attrition, which would optimize liberation for the particular coal under investigation at the coarsest possible particle size while limiting fines formation. It is important to note that when referring to liberation throughout this study, it implies the release, and separation, of entrapped coal particles from mineral inclusions with the intention of increasing the coal yield when washing it to the desired ash specification by density separation.

2. Experimental

Particle breakage was done on a Moatize run-of-mine coal from Mozambique. This coal was chosen because of its highly layered morphological structure consisting of coal seams interlayered with mineral matter. Compression breakage was simulated by using a garden roller (80 kg) to break the coal sample to top sizes of 13.2 mm and 6.7 mm. These sizes were achieved by placing the raw coal particles in a single layer in a steel frame with a specified height to prevent inter-particle breakage. The roller was then moved across the frame, crushing the coal to a specific top size. Impact breakage was done by using a locally manufactured drop weight impact rig (SANS 401:2010). The particles were again placed in a shallow frame with a specified height, and the dropped weight was stopped by the walls to ensure a specific top size. Top sizes for impact breakage were also 13.2 mm and 6.7 mm. Some sub-samples (after compression and impact breakage) were subjected to attrition in a laboratory tumbling mill at residence times of 1, 2 and 5 minutes. The tumbling mill had an outer diameter 380 mm and was rotated at 20 rpm (30 % of its critical speed) to ensure that only cascading motion occurred to prevent further impact breakage.

The coal yield improvement attained by the various combinations of breakage modes, and the washability properties, were investigated by a float-sink (densimetric) analysis of each sample. Particle size distribution analysis was performed, before and after each breakage event to evaluate the particle sizes formed due to breakage. Proximate analysis, free swelling index and calorific value determination were done on selected samples to determine these properties at different relative densities.

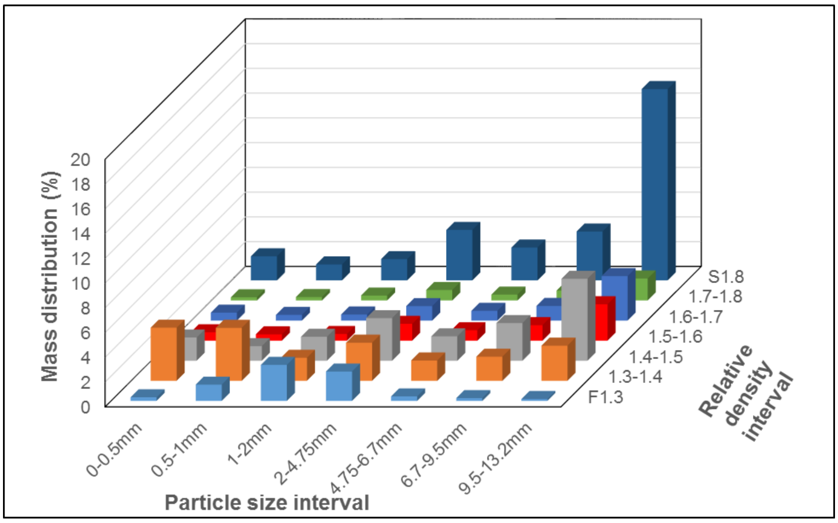

Figure 1: Size by washability graph for impact breakage to a top size of 13.2 mm with no additional attrition breakage.

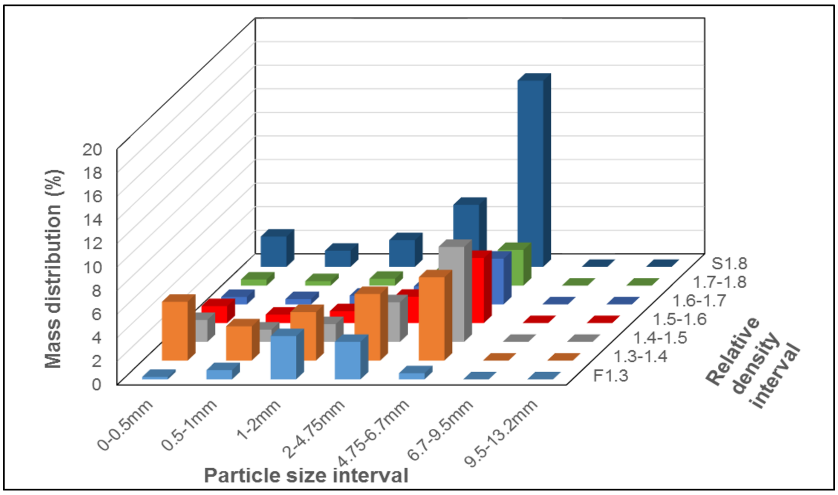

Figure 2: Size by washability graph for impact breakage to a top size of 6.7 mm with no additional attrition breakage.

3. Results and Discussion

Figure 1 shows, as an example, the size by washability data determined for the case of impact breakage to a top size of 13.2 mm with no additional attrition breakage, while Figure 2 is the size by washability graph for impact breakage to a top size of 6.7 mm with no additional attrition breakage. It presents the mass distribution of the whole sample as a percentage according to its relative density and particle size distributions. Note that the particle size range on the x-axis of

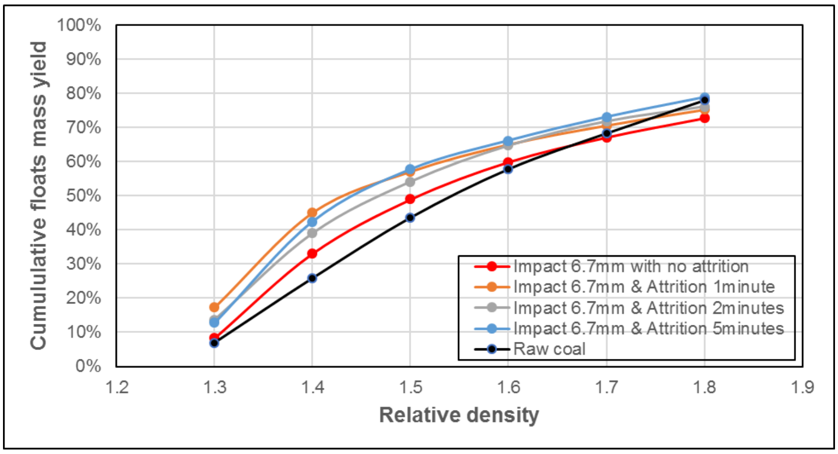

Figure 3: Densimetric curve for impact breakage to a top size of 6.7 mm.

Figure 2 was kept similar to that of Figure 1 for ease of readability and comparison.

The density fraction of interest was chosen to be the material with a relative density of less than 1.4 (occurring in the fractions F1.3 and 1.3 - 1.4), representing a "clean" product consisting mainly of liberated low density coal macerals. When comparing this material for the two cases, it was observed that the mass fraction of less than 1.4 RD material showed a slight increase when breaking to a top size of 6.7 mm as opposed to 13.2 mm. This can be attributed to the exposure and liberation of vitrinite-rich material when breaking to a smaller top size approaching some characteristic size of the morphological features.

Middlings, containing denser macerals as well as more mineral matter, occur in the relative density ranges of 1.4 - 1.8. It can be seen from Figures 1 and 2 that this material mainly occurs in the larger particle size ranges, indicating a lack of liberation. A large amount of middlings with particle sizes 6.7 - 13.2 mm are still present after breaking to a top size of 13.2 mm, but when further reduced to 6.7 mm, more low dense material appears, resulting in a yield increase of material in the relative density range lower than 1.4. When comparing the graphs for the material with a relative density of greater than 1.8, it occurs mainly in the larger particle size ranges regardless of the top size of breakage.

Compressive breakage showed similar results as for impact breakage; there was a slight increase in the amount of low density material by breakage to a top size of 6.7 mm compared to a top size of 13.2 mm. However, this increase was not as great as that for impact breakage case.

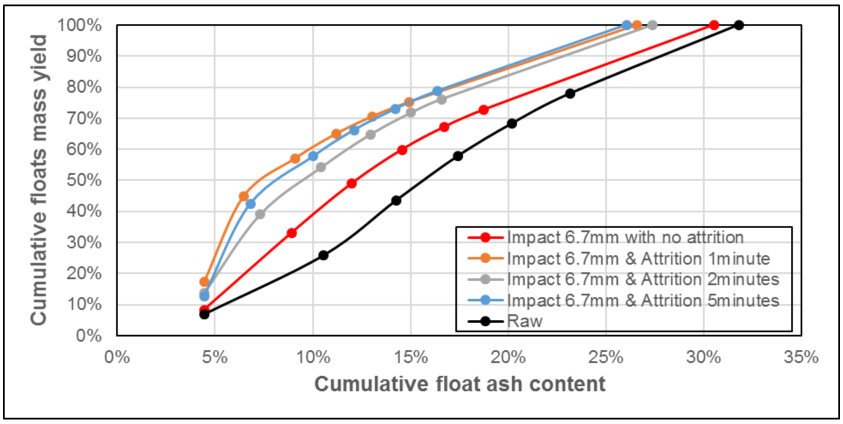

Figure 4: Ash curve for impact breakage to a top size of 6.7 mm.

Focusing on breakage to 6.7 mm, Figure 3 gives the densimetric information (cumulative float mass yield versus relative density) for the impact breakage case to a top size of 6.7 mm with and without different degrees of additional attritioning. The densimetric curve obtained for the raw un-sized coal is also shown as the black solid line.

It should be noted here that breakage to a top size of 13.2 mm did not show any marked difference in the densimetric curves compared to that of raw coal, even with additional attrition breakage, but Figure 3 shows that this was not the case for impact breakage to a top size of 6.7 mm. The effect of additional attrition can be explained by postulating that the initial breakage resulted in preferential breakage along the bedding planes, resulting in the exposure of vitrinite-rich material on the outsides of the particles. The brittle vitrinite-rich material was then chipped off and liberated from the exposed surface during attritioning. This resulted in an increase in the amount of material with a density of less than 1.4 RD and the yield of low density coal was thus increased. Breakage to a top size of 13.2 mm was insufficient to expose the morphological layers of material in this way.

Additional attrition breakage caused a 5 - 10 % yield increase for the material of 1.4 RD after impact breakage: for this density fraction, the cumulative float mass yield for the raw coal prior to any testing was 26 %, and impact breakage to 6.7 mm increased this to 33 %, while additional attritioning pushed it up to 45 %. On the other hand, the cumulative float mass yield for all experimental conditions, at a relative density of 1.8, were very similar.

Results in terms of the float mass yields achieved were similar for both impact and compressive breakage to 13.2 mm. Additional attrition after compressive breakage to 13.2 mm also had no significant effect on yield, but attrition after compressive breakage to 6.7 mm showed a slight increase in yield, although not as much as the increased yield after impact breakage to 6.7 mm followed by attrition. By comparing all the test conditions including top size, applied breakage mode and attrition residence time, it can be concluded that impact breakage to a top size of 6.7

mm followed by attrition breakage for 1 minute resulted in the greatest increase in cumulative floats mass yield.

Figure 4 shows the ash curve for impact breakage to a top size of 6.7 mm, as well as for the raw coal prior to testing.

Impact breakage to 6.7 mm resulted in an increase in the cumulative floats mass yield at the lower ash values. The cumulative floats mass yield obtained in this case showed a substantial increase compared to that for raw coal, and the effect of additional attrition was clear. This can again be ascribed to the exposure and liberation of vitrinite-rich material when breakage is to a smaller top size. For example, at a cumulative float ash of 10 %, the yield increased from 26 % for the uncrushed coal to 61 % with attrition breakage for 1 minute. Additional attrition for longer than 1 minute did not improve the yield any further, showing that the chipping off of brittle vitrinite rich components happened rapidly.

Both impact- and compressive breakage to 13.2 mm did not show any increase in the cumulative float mass yield compared to that of the raw coal prior to testing.

Compressive breakage to a top size of 6.7 mm followed by attrition breakage, also resulted in an increase in the cumulative floats mass yield compared to that of the raw coal. The increase is, however, not as substantial as that for impact breakage to a top size of 6.7 mm followed by attrition breakage. The highest cumulative floats mass yield attained at a cumulative float ash yield of 10 %, for compressive breakage to a top size of 6.7 mm was 49 %, for the sample subjected to 2 minutes of attritioning. This was much lower than for impact breakage followed by 1 minute of attritioning, which gave a yield of 61 %. It is thus deduced that the impact crushing mode caused more "delamination" of the morphological layers to expose the high value component band for easier removal by mild attrition.

Of course, a valid argument against finer crushing is the concern about the generation of fines. A convenient way to quantify this is to construct a liberation curve to evaluate the mass fraction of material with relative density of for example 1.4 (related to some arbitrary low ash product) versus particle size, for each of the breakage modes combinations (Figures 5 and 6). (Note that the cumulative mass yield is expressed as a percentage of total mass, and not just the material od relative density <1.4.) It was observed that both impact and compressive breakage to 13.2 mm yielded similar results, indicating that there was not significant effect of the mode of breakage on larger particles on the particle size distribution of the valuable fraction lighter than 1.4 RD fraction. Additional attritioning also had no significant effect. Breakage to this size was not sufficient to expose all the valuable components trapped between mineral bands. Breaking to 6.7 mm both by impact and compression however increased the yield of fine low density material, and additional attrition breakage again had a substantial effect. Again, this observation can be ascribed to breakage to a top size of 6.7 mm exposing more of the coal macerals which was then released as fines during attrition breakage. The expected particle size distributions of the material lighter than 1.4 RD material can also be deduced from Figures 5 and 6.

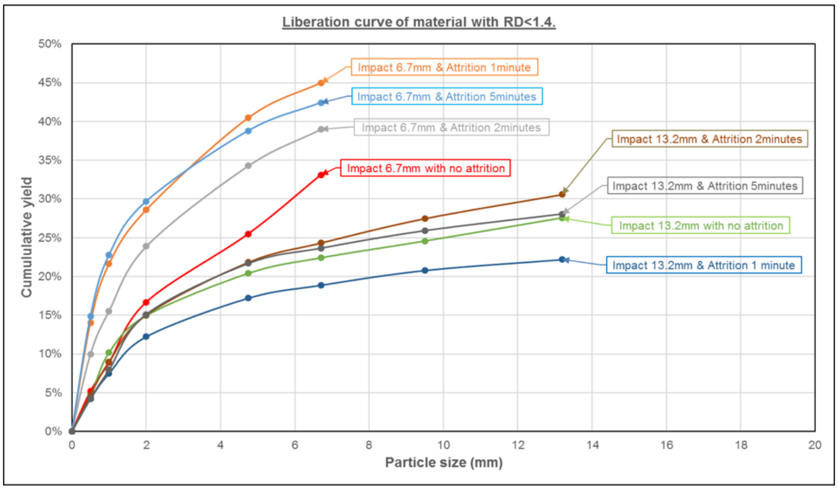

Figure 5: Liberation curve for impact breakage. Note that the cumulative mass yield is expressed as a percentage of total mass, and not just the <1.4 RD material.

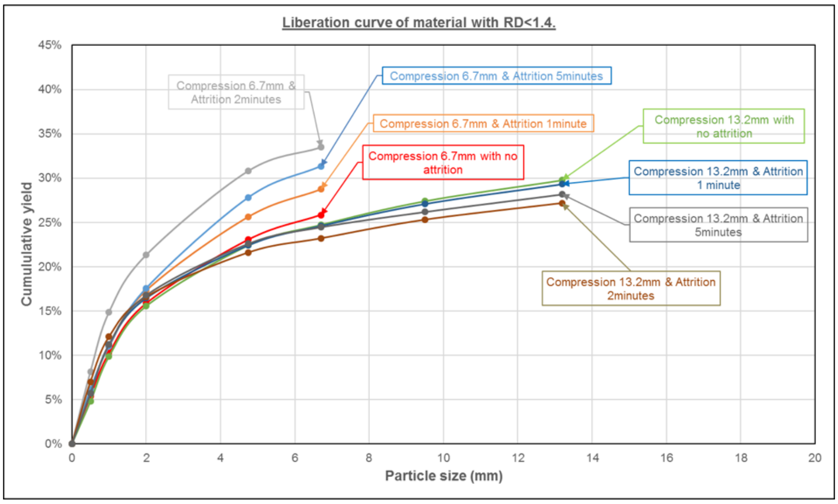

Figure 6: Liberation curve for compressive breakage. Note that the cumulative mass yield is expressed as a percentage of total mass, and not just the <1.4 RD material.

Table 1 shows a summary of the yield improvements obtained to produce for example a 10% ash product for all the different breakage modes and sequences tested. Crushing, by either mode, to 13.2 mm did increase the yields slightly, and attritioning did not have a marked effect. Crushing to 6.7 mm generally improved the yields, but the optimum cases are highlighted in the table, being impact crushing to 6.7 mm, followed by some mild attritioning, ideally around 1 minute.

It must be kept in mind that different samples, all taken from the original population, were used for the different experiments, therefore minor sampling split errors might have occurred.

Table 1: Summary of yield improvements obtained to produce a 10% ash product

Experimental conditions			To produce a 10% ash product		Yield improvement	
Type of breakage	**Top size mm**	**Attrition time min**	**RD required**	**Yield %**	**Absolute increase**	**% Increase**
Uncrushed		-	1.39	24.2	-	-
Impact	13.2	0	1.44	35.8	11.6	47.9
		1	1.43	27.2	3.0	12.4
		2	1.43	35.6	11.4	47.1
		5	1.43	34.1	9.9	40.9
	6.7	0	1.44	38.7	14.5	59.9
		1	1.45	60.5	36.3	150.0
		2	1.49	52.1	27.9	115.3
		5	1.50	57.6	33.4	138.0
Compression	13.2	0	1.43	36.0	11.8	48.8
		1	1.45	38.5	14.3	59.1
		2	1.45	36.4	12.2	50.4
		5	1.44	35.6	11.4	47.1
	6.7	0	1.46	37.0	12.8	52.9
		1	1.46	40.9	16.7	69.0
		2	1.49	47.9	23.7	97.9
		5	1.48	45.2	21.0	86.8

4. Conclusions

Results of impact breakage and compressive breakage to the top sizes of 6.7 mm and 13.2 mm were investigated, as well as the cases where the initial breakage mode was followed by additional breakage using autogenous attritioning at different residence times. Results obtained have indicated that impact breakage as well as compressive breakage to a top size of 13.2 mm had no significant effect on increased valuable coal yield, as compared to the coal prior to any testing. Both impact breakage and compressive breakage to a top size of 6.7 mm resulted in a coal yield enhancement. Particularly, the coal yield was substantially increased by impact breakage to a top size of 6.7 mm. It was concluded that impact breakage resulted in a greater coal yield enhancement of material with RD < 1.4, compared to compressive breakage. Impact breakage thus resulted in a larger proportion of liberated coal with RD < 1.4.

Attrition breakage additional to impact breakage to a top size of 6.7 mm resulted in an even further increase in the coal yield. This is because impact breakage to a smaller top size of 6.7 mm exposed more valuable coal macerals. There could be sheared off from the parent particles during attrition resulting in a higher amount of material with RD < 1.4. Additional attrition after crushing to 13.2 mm did not show any noticeable effect on the coal yield.

Sufficient liberation for the coal used during this study was defined as the largest particles size with the maximum allowable ash yield obtained to produce a product as required by market specifications, and was arbitrarily taken as 10%. This target ash condition was used to predict the overall cumulative yield that can be obtained by back-calculation, and to estimate the required relative density for separation to obtain the hypothetical ash yield. Impact breakage to a top size of 6.7 mm followed by attritioning for 1 minute resulted in a cumulative yield of 61 % compared to that of the raw coal which was 24 %. Thus, the optimum result was found using impact breakage to 6.7 mm followed by mild attrition breakage for 1 minute to give an absolute coal yield increase of 36 % of a product of relative density of 1.54 and a target ash yield of 10 %.

It was concluded that the most effective combination of breakage modes applied to optimize the coal yield was impact breakage to a top size of 6.7 mm followed by attrition breakage for 1 minute. The residence time for attritioning must be a minimum to minimize fines generation.

5. Acknowledgements

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