International Journal of Mining Science and Technology 23 (2013) 669–674

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Liberation characteristics of coal middlings comminuted by jaw crusher and ball mill

Xie Weining [a], He Yaqun [a,b,*], Zhu Xiangnan [a], Ge Linhan [a], Huang Yajun [a], Wang Haifeng [a]

[a] School of Chemical Engineering and Technology, China University of Mining & Technology, Xuzhou 221116, China
[b] Advanced Analysis & Computation Center, China University of Mining & Technology, Xuzhou 221116, China

ARTICLE INFO

Article history:
Received 23 December 2012
Received in revised form 10 January 2013
Accepted 12 February 2013
Available online 31 August 2013

Keywords:
Coal middlings
Fragmentation force
Liberation
Float and sink test
Sectional micrograph

ABSTRACT

The associated minerals make coal middlings possess a relatively high ash content. Subsequent liberation through size reduction can cause recovery increase. However, effect of comminution facilities on mineral liberation of middlings was ignored. This paper studied the liberation characteristics of middlings crushed with different kinds of fragmentation forces. Middlings of −3 mm + 0.5 mm sampled from a dense medium cyclone were comminuted by a jaw crusher and a ball mill to −0.5 mm with similar size distribution respectively. The generating mechanism of fines was also analyzed. Full densimetric analyses indicate that mineral liberation of the product crushed by the jaw crusher is better than that by the ball mill at each fraction. For sizes of −0.125 mm + 0.074 mm and −0.074 mm, yields of the product with ash content 11% comminuted by jaw crusher are nearly 20% higher than that by the ball mill. Sectional micrographs observed by the scanning electron microscopy (SEM) also show the same law for these two fractions and some intergrowth particles still exist in the fraction of −0.5 mm + 0.25 mm.

1. Introduction

The rapid growth of economy leads to the tremendous energy challenge that the world will face, especially for China. As a developing country with coal as the main resource, enormous energy consumption directly leads to the shortage of coal. Producers, therefore, are looking to maximize the recovery of saleable coal from raw coal to meet the huge market demand. Generally speaking, raw coal is separated into clean coal, middlings and gangue by different preparation methods. In China, middlings normally accounts for nearly 20% of rough coal and generally has an ash content of 20–40%. Without any retreatment, middlings was directly used as fuel in power plant, which might lead to energy waste and environmental problems due to sulfide ore associated in coal.

Associated minerals make middlings possess relatively high ash content, thus it is not suitable for the demand of saleable quality. Liberation of minerals from middlings through size reduction and the subsequent preparation are important to upgrade recovery and to promote economic benefit [1,2]. In general, size reduction will result in mineral liberation [3,4]. As to improve the clean coal recovery, size of comminution product must be suitable for retreatment, otherwise the new generated fine coal will be themselves problematic [5–9]. Compared with the extremely fine liberation size for metal mine, mineral liberation size of coal middlings is relatively coarse due to the characteristics of the associated minerals, and the low limit of separation size for coal is comparatively higher than that of metal ores [10–13]. Therefore, size of the crushed product should be strictly controlled and preferential breakage which occurs at boundary between the associated minerals and coal is required during the comminution process.

Various kinds of comminution devices have been developed according to different fracture mechanisms. For the conventional comminution facilities, it is believed that crusher, ball mill and stirred mill utilize crushing, impact and abrasion forces to realize size reduction respectively [14,15]. In recent years, high voltage pulses and electrical disintegration are also employed for experimental study of coal liberation. Ito et al. compared the comminution behavior of coal using an electrical disintegration and a roll crusher respectively, and reported that cracks were generated at minerals and coal boundaries and good liberation can be achieved even in the coarse fractions with the electrical disintegration [16]. Wang et al. reported the studies on the mineral liberation by high voltage pulses and conventional comminution with the same specific energy levels [17]. The experimental results indicated that the electrical comminution was a potential method to use less energy generating similar liberation degree with selective fragmentation of mineral ores as in the mechanical comminution [18]. To recover more clean coal, some coal preparation plants crushed coal middlings to −3 mm and separated progeny with the combined flow sheet of gravity separation and flotation [19]. Although the retreat-

* Corresponding author. Tel.: +86 15162116750.
E-mail address: yqhe@cumt.edu.cn (Y. He).

2095-2686/$ - see front matter © 2013 Published by Elsevier B.V. on behalf of China University of Mining & Technology.
http://dx.doi.org/10.1016/j.ijmst.2013.08.009

ment of coal middlings can improve the economic benefit, effect of comminution facilities on liberation characteristics of coal is ignored. Compared with the metallic mineral, the value of coal is relatively low, and process cost for clean coal recovery should be considered in the selection of comminution and the subsequent separation devices for middlings.

The work outlined in this study is to investigate the effect of different kinds of fragmentation forces on the mineral liberation of coal middlings. Considering the low limit of separation size for coal, a jaw crusher and a ball mill were selected as the experimental devices to achieve the similar size distribution of the product. Full densimetric analyses and sectional micrographs on sized fractions of coal middlings prior to and after comminution were conducted to compare the discrepancy of liberation degree between these two methods.

2. Experimental

2.1. Samples

In China, the coking coal is paucity and its reserve is only 25.81% of the total. Due to the strict quality requirement of coking coal for steelmaking industry, clean coal with low ash content is produced and at the same time, nearly 20% middlings is generated with 20–40% ash content at the same time. Fig. 1 shows the yields of coking coal middlings in recent years, which reached 0.12 billion ton in 2011, thus it is meaningful for the retreatment of coking coal middlings to save energy resource. So, coking coal middlings was chosen as the experimental material which was sampled from a coking coal preparation plant. In this study, middlings with size of −3 mm + 0.5 mm was selected to represent the sampled middlings as a larger reduction ratio generally means the higher liberation degree when size of the comminution product was −0.5 mm [20]. It was different with the liberation characteristic research of coal middlings undertaken by Oliver et al., in which size of material comminuted by swing hammer crusher ranged from 25 to 150 mm [21].

2.2. Comminution of coking coal middlings

Two kinds of comminution devices, the jaw crusher and ball mill, were utilized to compare the effect of different kinds of fragmentation forces on mineral liberation on the condition of similar size distribution of the product. For the jaw crusher, closed circuit comminution was employed to verify the product size below −0.5 mm at the smallest discharge. The ball mill utilized in this study was a cylindrical mill with size of D350 mm × L250 mm. 40 kg steel balls of −35 mm + 20 mm were selected and each experiment was performed at the material mass concentration of

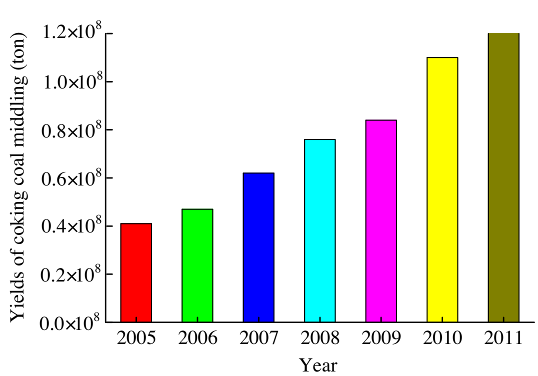

Fig. 1. Yields of coking coal middlings in China in recent years.

Table 1
Parameters used for the semi-theory formula.

Size fraction (mm)	d (mm)	K_c	σ (kg·cm^{-2})	ρ_e (g cm^{-3})	D_0 (cm)	ψ
−1 + 0.5	0.94	3.49	80	6.49	31.69	0.91
−0.25 + 0.125	1.92	2.00				
−0.125 + 0.074	2.67	1.74				
−0.074	2.91	1.74				

70%. As size distribution of the product ground by the ball mill was widely effected by the ball diameter, ball diameter ratio, grinding time, rotation rate and adding ball rate, the semi-theoritic formula based on the principle of fragmentation mechanics was applied to guide the grinding process [22]. The semi-theoritic equation is shown as follows:

$$D_b = K_c \frac{0.5224}{\psi^2 - \psi^6} \sqrt[3]{\frac{\sigma}{10\rho_e D_0}} d \quad (1)$$

where D_b is the diameter of certain steel ball which is suitable for a certain particle size d; K_c the comprehensive empirical correction coefficient; ψ the rotation rate; σ the uniaxial compressive strength of the rock; ρ_e the effective density of steel ball in slurry; D_0 the diameter of intermediate aggregation layer of steel balls in mill; and d the diameter with the cumulative yield of 95% in each size fraction. Parameters employed in this formula are shown in Table 1.

2.3. Techniques

Size distribution of middlings and the comminution product were sieved. The float and sink test was conducted to obtain the variation of density distribution between coking coal middlings and the comminution product. For middlings of −3 mm + 0.5 mm, density solutions of 1.30, 1.40, 1.50, 1.60, 1.80 kg/L with different proportions of $Zncl_2$ and water were utilized according to the National Standard of Float and Sink Analysis of Coal (GB/T 478-2001). Float and sink analyses for the comminuted product of sized and unsized were performed in a centrifuge with rotational speed 3000 r/min for 12 min. Density distribution for coal fines was the same, while the heavy liquid was the mixture of benzene, carbon tetrachloride and tribromomethane. Ash contents of coal middlings, sized and unsized particle of the product were measured with a muffle furnace. Sectional micrographs of coal middlings and the sized product were carried out with the FEI Quanta™ 250 scanning electron microscopy (SEM). Both parent and progeny particles were washed firstly with ethyl alcohol to remove the unexpected fines [23]. Then 20 g epoxy resin with a mixed proportion of 70:30 for Epothin epoxy resin (20-8140-128) and Epothin epoxy hardener (20-8142-064) were poured into a plastic container which includeds 4–5 g samples. As epoxy adequately mixed with the samples, Buehler vacuum impregnation pump was employed to remove bubbles from the liquid to prevent negative effect on the further micrographs observed by the SEM. Samples were solidified about 24 h later and were removed from the container to be polished. As the ordinary epoxy resin and pure coal phase were carbonate material with the very close average atomic weight, the SEM parameters were adjusted to achieve the easy distinction between pure coal and background [24,25].

3. Results and discussion

3.1. Particle size distribution

Table 2 indicates the size distributions of raw coal and the grinding media which is suitable for each size fraction calculated