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Research on the Ultrafine Crushing Technology of Ultralow Ash Taixi Anthracite in Stirred Mill

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Abstract: With ultralow ash Taixi anthracite chosen as object of research, the influence of milling time on crushing effect of ultralow ash Taixi anthracite in stirred mill is analyzed. Laser particle-size analyzer is adopted to analyze particle size distribution of products, based on which the crushing process of ultralow ash Taixi anthracite in stirred mill is analyzed. The result shows that ultralow ash Taixi anthracite undergoes the process of "crushing-reunion-break apart" in stirred mill and optimum milling time is 70 min; at the same time, selective crushing occurs in stirred mill and crushing model accords with surface crushing model, so the theory that ultralow ash Taixi anthracite accords with selectivity-surface crushing model is put forward.

Key words: Crushing model, mechanism, stirred mill, ultrafine crushing

INTRODUCTION

Taixi anthracite belongs to the coal measure strata of Jurassic Period Yan'an Formation and is high-metamorphosed and high-quality anthracite with well-known characteristics such as ultralow ash (clean coal <3%), ultralow sulphur (clean coal <0.1%), high carbon content (about 90%), high chemical activity and high electrical resistivity (Zhang *et al*., 2009). During recent years, people are attaching more attention to material research of coal. Taixi ultralow anthracite is a kind of high-quality coal-based material. The preconditions of coal material research are to conduct ultrafine crushing process on anthracite (Choi *et al*., 2009; Choi *et al*., 2007; Choi and Choi, 2003). Especially for ultralow ash Taixi anthracite featuring little mineral substance and relatively fine disseminated grain size, only after ultrafine process, the anthracite can be effectively separated and purified from impurity (Xiao and Zhang, 2010; Fu *et al*., 2005; Wu *et al*., 2010; Chen, 2010), so as to reach the objective of material application. The author used stirred mill to conduct ultrafine crushing process on ultralow ash Taixi anthracite, studied the influence of crushing time on crushing effect and made analyses and predictions on crushing process, mechanism and model.

ULTRAFINE CRUSHING

Most current crushing methods are mechanical comminution which belongs to crack crushing. The most important characteristic of crack crushing is force and energy. With the increase of crushing strength, particle will become minor and fine, namely particle size becoming smaller and size distribution narrowing. While the particle becomes minor and fine, the particle accumulation will become increasingly loose, the apparent density and tap density of powder will decrease, compression degree and porosity will increase, the powder liquidity will become poor and rotation resistance (namely, the body resistance and frictional resistance) will decrease. However, the mutual attraction among powder particles will increase and particle surface energy will increase.

After impact for one time, the relatively large particles will become several small particles, superficial area will increase greatly and the crushing effects are significant; however, after impact for one time, the superficial area of minor particles will increase relatively small and the crushing effects are relatively low which are especially obvious in the initial stage of crushing. However, extrusion, shear and grinding cause spalling of material

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surface, thus producing incomplete crushing. If the particle is smaller, the superficial area of extrusion, shear and grinding will be larger and the speed during crushing later stage will be faster. It can be concluded that it is a good method for mechanical method to use comprehensive force application methods of impact, extrusion, shear and grinding to realize ultrafine crushing (Zhang and Wu, 2011).

The stirred mill is one of the most promising equipments among ultrafine crushing equipments and ultrafine grinding devices which have high energy efficiency (Zhang and Wu, 2011). Its grinding room is filled with small-diameter crushing medium and is equipped with stirring apparatus. By the aid of extrusion force among crushing medium and the force application methods of mutual impact, friction, shear and grinding, the materials are crushed, so as to achieve the effect of homodisperse.

EXPERIMENTAL SECTION

Material and analysis: The ultralow ash Taixi anthracite used in the experiment is cleaned coal which undergoes jigging and heavy medium washing conducted by Taixi coal preparation plant. The particle size is 0.5-6 mm. For the analysis result of coal quality, see Table 1. The ultralow ash Taixi anthracite is such a kind of high-quality coal which features low water, low ash (2.59%), high fixed carbon content (about 89%) and low sulphur (about 0.10%).

The analysis result of coal petrography maceral is shown in Table 2. The main maceral of ultralow ash Taixi anthracite is vitrinite. The second is inertinite. Exinite is not detected; mineral contents are few in the coal sample. The main mineral species are carbonate mine and clay mineral.

Experiment method: Use test sample-preparation grinder to roughly crush sample of ultralow ash Taixi anthracite to the degree<1 mm. The ultrafine crushing experiment should be conducted in stirred mill developed by Xi'an University of Science and Technology, with Zirconium ball as crushing medium (single particle size 3 mm); dry crushing is adopted. Under the condition that rotate speed is 300 r min^{-1} and mass ratio of medium ball and coal is 20:1, change milling time and adopt American Beckmann LS230 Laser particle-size analyzer to determine size distribution of processed particles at different time.

RESULT AND DISCUSSION

Influence of milling time on crushing effect: Table 3 shows the result of ultrafine crushing experiment of ultralow ash Taixi anthracite in stirred mill. From Table 3, the following conclusions are got: the particle size is becoming smaller as time extends; when the crushing time is 70 min, D97 can reach about 10 μm; when the crushing time increases to 90 min, agglomeration occurs in product particles, causing the significant increase of particle size; along with the continuous progress of crushing, agglomeration particles are broken apart again, resulting in the decrease of particle size.

Crushing process mechanism and model prediction: Figure 1 shows the change curve of size distribution during crushing process of stirred mill. From analysis of Fig. 1, product size distribution of stirred mill features from double-peak to multi-peak. As the milling time increases, the whole curve moves toward fine particle size and the lower limit of particle size of coarse particle diameter peak moves forward along with it, demonstrating that during the crushing process, coarse particles undergo process of grinding and surface peeling and are gradually crushed into fine particles. Therefore the process accords with surface crushing model. Figure 2 shows the change of accumulated size distribution during the crushing process of stirred mill. From the analysis of Fig. 2: As the milling time increases, the change tendency of the curve of product accumulated particle size distribution is similar to the size distribution of surface crushing model (Weinstein and Snoby, 2007) which also demonstrates crushing process of stirred mill accords with surface crushing model. The reasons may be as follows:

Table 1: Coal Quality Analysis of Ultralow Ash Taixi Anthracite

Technical analysis [%]				Elemental analysis [%], daf				
Mad	Ad	V daf	FC, d	C d	H d	N d	O d	S t, d
1.81	2.59	7.36	88.61	90.93	3.50	0.81	2.08	0.09

Table 2: Coal petrography maceral analysis of ultralow ash taixi anthracite

De-mineral base			Contain mineral base				
Vitrinite	Inertinite	Exinite	Organic component	Clay mineral	Sulfide mineral	Carbonate mine	Monox mine
58.5	41.5	0.0	98.3	0.8	0.0	0.9	0.0

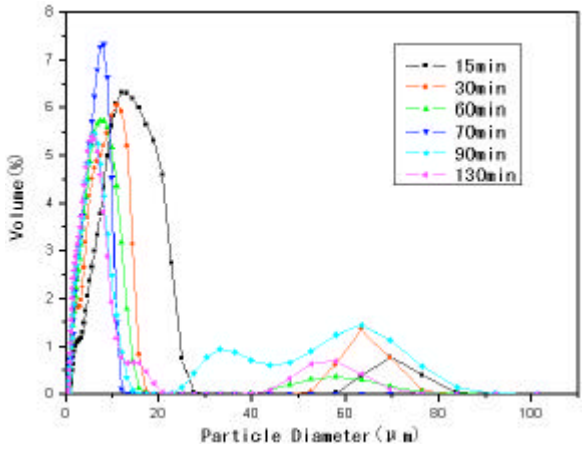

Fig. 1: Change of size distribution during crushing process of stirred mill

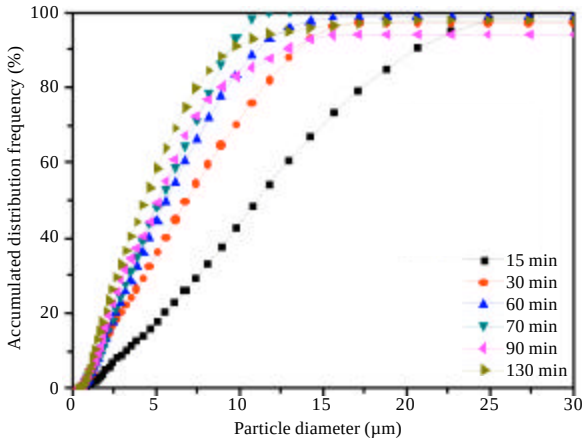

Fig. 2: Change of accumulated size distribution during crushing process of stirred mill

The medium particle size in stirred mill is small, so the force of impact is little which can only cause local crushing on particle surface but is not able to cause volume crushing. In the crushing process of stirred mill, abrasive power is the main power.

Table 4 shows the result of ultralow ash Taixi anthracite coarse particle diameter peak's corresponding particle accumulated volume fraction in stirred mill. From the analysis of results of Fig. 1 and Table 4, stirred mill product has obvious coarse particle diameter peak and coarse particle diameter peak moves forward along with the progress of crushing process which demonstrate that selective crushing occurs during crushing process of ultralow ash Taixi anthracite. When crushing time

Table 3: Result of ultrafine crushing experiment of ultralow ash taixi anthracite in stirred mill

Time, min	D50, μm	D90, μm	D97, μm
15	11.07	20.60	24.47
30	6.98	14.50	17.10
60	5.62	11.13	13.80
70	5.24	9.32	10.48
90	5.18	25.87	64.90
130	4.38	9.71	17.40

Table 4: Coarse particle diameter peak's corresponding particle accumulated volume fraction result in stirred mill

Volume fraction (%) Milling time (min)	Lower limit of particle size (μm)	Upper limit of particle size (μm)	Volume fraction (%)
15	57.77	92.09	1.66
30	39.78	92.09	2.90
60	36.24	101.10	2.62
90	20.71	111.00	11.60
130	39.78	83.89	2.31

Upper limit of particle size-starting point of distribution curve; lower limit of particle size-droppoint of distribution curve

increases to 70 min, coarse particle diameter peak disappears. The reasons are as follows: Along with the progress of crushing process, materials difficult to be crushed into fine particles will also be crushed into fine particles (Gupta *et al*., 2012). When crushing time extends to 90 min, the particles will undergo agglomeration, causing the increase of volume fraction of coarse particle diameter peak. However, as the milling time increases further, parts of agglomeration particles will be broken apart again and undergo crushing. Therefore, the coarse particle diameter peak moves forward fine particle size.

According to the analysis of the said crushing process, ultralow ash Taixi anthracite undergoes selective crushing and surface crushing and its selectivity-surface crushing model is put forward, as shown in Fig. 3. In Fig. 3, the united parts consisting of crushing resistant components and easy crushing components are used for explanation. Before crushing, coal sample is often a united part of many components, while the crushing difficulty level of different components is different. Some components are easy to be crushed and for these components the probability of crushing is relatively high during crushing process and the components which are crushed are many; some components are hard to be crushed and for these components the probability of crushing is relatively low during crushing process and the components which are crushed are few. Along with the progress of crushing, the particles easy to be crushed will be crushed earlier and the remaining is the particles hard to be crushed. Along with the progress of crushing, the remaining continues to be crushed. Finally all the particles will be crushed completely.

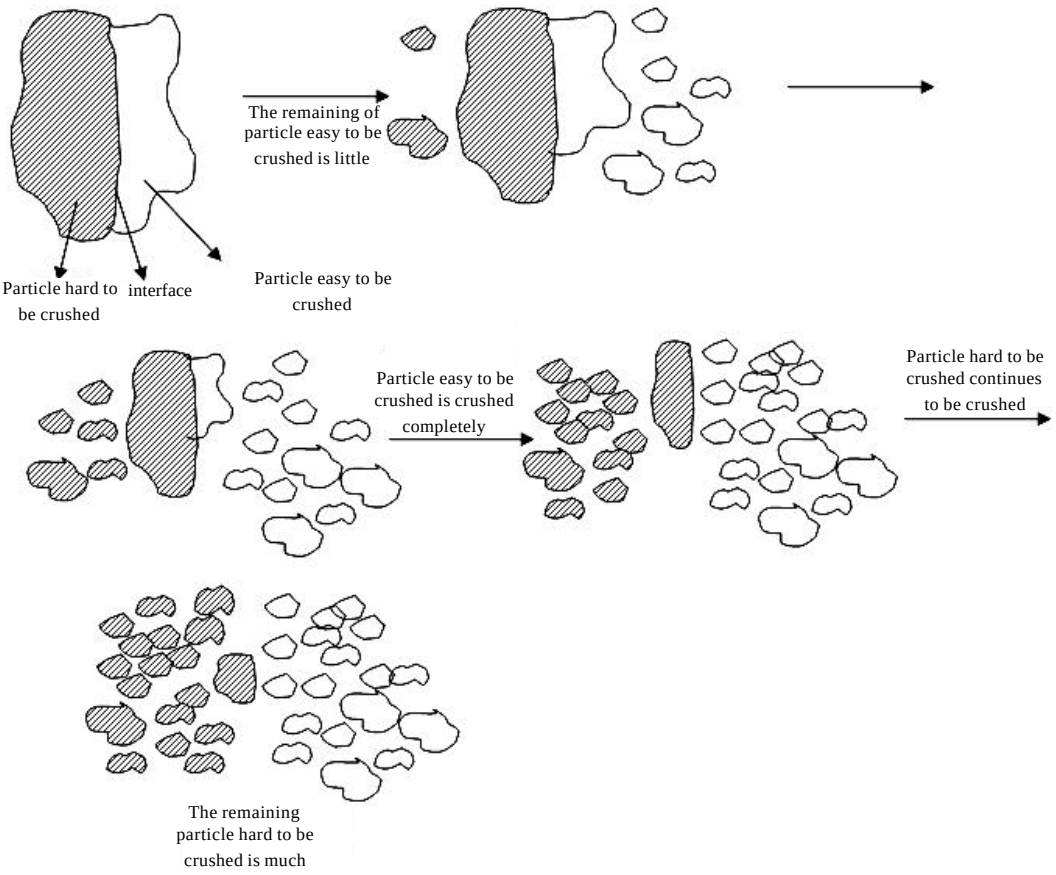

Fig. 3: Ultralow ash Taixi anthracite's selectivity-surface crushing model in stirred mill

CONCLUSION

The research, through carrying out the analysis of the influence of crushing time of stirred mill on Taixi anthracite crushing result, has conducted analysis and prediction on crushing process, mechanism and model and discussed key technologies and problems on ultrafine crushing of Taixi anthracite when stirred mill is used as crushing function element. Now, main conclusions are as follows:

When ultralow ash Taixi anthracite undergoes ultrafine crushing for 70 min, D97 of about 10μm can be got and the anthracite undergoes process of "crushing-reunion-break apart" in the stirred mill.

Ultralow ash Taixi anthracite undergoes selective crushing in stirred mill and accords with surface crushing model, so the theory that ultralow Taixi anthracite accords with selectivity-surface crushing model is put forward.

Using Taixi anthracite as raw material to conduct relevant high new coal-based material research is one of the effective ways to extend industrial chain and improve additional value. Thereinto, ultrafine ultrapure technology has been the bottleneck for the development of coal-based material. The research, on the background of effective development of anthracite, carries out the research of selectivity ultrafine crushing technology and can provide research foundation for giving full play to coal structure and property in aspect of high-efficient utilization of coal. While the further research of Taixi anthracite ultrafine ultrapure technology is promoting Taixi anthracite in the development of new material industry to achieve good economic benefits, it also has great significance for realizing the strategic west transfer of China's coal industry and promoting comprehensive development of ultrapure coal undertaking.

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