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Role of surface roughness in the attachment time between air bubble and flat ultra-low-ash coal surface

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ABSTRACT

Surface roughness plays an important role in the floatability and wettability of mineral and coal particles. However, the role of surface roughness in the floatability of coal particles has not been sufficiently investigated because coal consists of organic and inorganic materials. This paper is to obtain some insights into the role of surface roughness in the coal surface wettability. In this investigation, Taixi ultra-low-ash coal particles, with ash content of 1.55%, were polished and the polished flat coal surfaces with various roughness were obtained. The attachment time between air bubble and flat coal surface were tested at the water solution without flotation reagents. Throughout this paper, it was found that the attachment time increased with the increase of roughness of coal surface. The attachment area between bubble and flat coal surface was decreased with the increase of surface roughness. The attachment between bubble and flat rough coal surface was unstable, compared to the attachment between bubble and smooth coal surface. The rougher coal surface makes the detachment between bubble and coal surface easier than the smoother coal surface. The higher the roughness of coal surface is, the more pores and grooves the coal surface has. The pores, gaps and grooves are filled up with the water in the slurry and have negative effects on the attachment between bubble and flat coal surface.

1. Introduction

The floatability of mineral surface usually corresponds to the hydrophobicity and wettability of mineral surface. As is known, a higher hydrophobicity and lower wettability of mineral surface mean this mineral surface has a higher floatability. The hydrophobicity and wettability of mineral surface are usually characterized using the contact angle measurements. For example, a higher water contact angle on mineral surface usually represents a higher hydrophobicity and lower wettability of mineral surface. However, the flotation process is not only determined by the hydrophobicity and wettability of mineral surface, but also affected by other factors, such as bubble size, particle size, flotation energy input, intensity of turbulence and so on. Throughout these influential factors, the bubble-particle attachment and detachment should have the fundamental role in the flotation performance.

The bubble-particle attachment time consists of three parts of time (Nguyen et al., 1998). The first part of time is the induction time which is for the liquid film to be thin and reach to a critical film thickness. The second part of time is for the film to be ruptured and then form the three-phase contact nucleus. The third part of time is for the three-phase contact (TPC) line to expand from the critical nucleus radius to build a stable wetting perimeter. Usually, the second part of time is significantly shorter than the first and third ones. In many published studies, the induction time is considered as the attachment time in the experimental measurements using the induction measurer. The measuring of these three parts of time has not reached a unified point of view in the published reports. It is acceptable the second part of time, which is for the film to be ruptured and then form the three-phase contact nucleus, is ignored. However, the time for the expansion of the three-phase contact line cannot be ignored because it represents the difficulty in the formation and expansion of the three-phase contact line on the rough and heterogeneous surface of minerals.

The particle-bubble attachment time is greatly affected by the roughness of mineral surface. Dippenaar (1982a, 1982b) found the attachment time between smooth sulphur surface and bubble was bigger than that between rough sulphur surface and bubble. Krasowska and Malysa (2007a, 2007b) found the higher roughness of Teflon surface could help the quick expansion of the three-phase contact line. Similar findings were also found in Fluorite surface because the time of TPC expansion on rough Fluorite surface was shorter than that on smooth Fluorite surface. It is believed that the rougher surfaces can accelerate the formation of critical thickness of liquid film and also entrap air at the rougher surfaces as well as make the rupture of liquid film easy and quick (Albijanic et al., 2010). However, the time of TPC expansion may be bigger if the entrapped air at the rougher surfaces is dissolved

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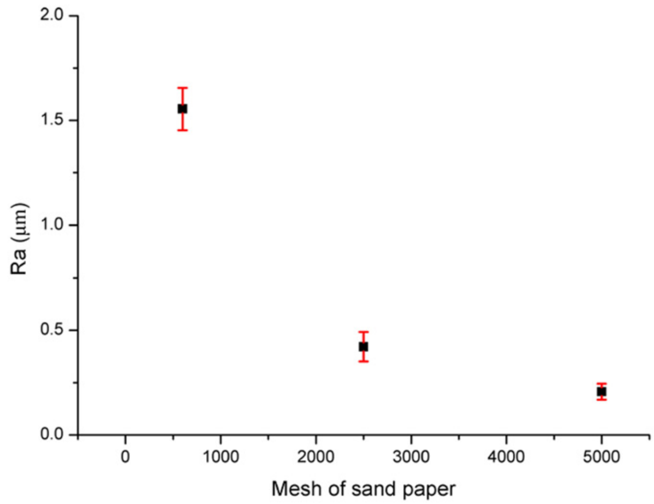

Fig. 1. Flat coal surface roughness after different meshes sand paper polishing.

as the water will fill the pores and grooves. The water-filled pores and grooves may have a negative role in the formation and expansion of the three-phase contact line on the rougher and heterogeneous surface of minerals. It is necessary to investigate the effect of surface roughness on the bubble-particle attachment time. It has been observed that the surface roughness can affect the flotation performance of quartz, barite and glass beads and complex sulphide ores (Ulusoy et al., 2003; Guven et al., 2015a, 2015b; Karakas and Hassas, 2016; Hassas et al., 2016; Guven et al., 2016).

In addition, it is difficult to study the accurate coal-bubble attachment time because coal is usually heterogeneous as a mixture of organic and inorganic materials. For example, the bubble-particle attachment time measurement is found to be dependent on the particle composition of copper-sulphide ore (Albijanic et al., 2011). The existing published papers regarding the coal-bubble attachment time are not very sufficiently. This paper is to investigate the effect of surface roughness on the attachment time between air bubble and flat coal surface. Taixi ultra-low-ash coal particle, which has very low ash content (<2%) and is considered as pure coal, were used to ensure the progress of this study.

2. Experimental method and procedure

2.1. Materials

Ultra-low ash coal samples were selected from Taixi Coal Preparation Plant in Ningxia province of China. The Taixi coal is anthracite. The contents of elements (C, H, O, N, and S) based on dry ash free are 94.43%, 3.73%, 0.91%, 0.79% and 0.13%, respectively. The ash content of selected ultra-low ash coal samples is 1.55% which is very low and the coal samples can be considered as ultra-low-ash coal. It is considered that each coal particle has its similar surface property (Xia et al., 2016). Lump coal particles were selected for the experimental samples in this investigation and were forwarded to the polishing treatments in order to obtain various flat coal surfaces with various surface roughness values.

2.2. Polishing treatment

In order to gain the flat surfaces of coal particles with various surface roughness, lump coal particles were polished using different sand papers with various meshes by hand. The sand papers were made by MATADOR in Germany. The meshes of sand papers surface are 600, 2500 and 5000. Based on the sand papers with various meshes, the flat surfaces of coal particles with various surface roughness values were gained. These flat coal surfaces with various surface roughness values were used in the surface roughness, SEM, contact angle and attachment time measurements.

2.3. Surface roughness measurement

The Mitutoyo SJ-210 surface roughness measurer was used to measure the surface roughness of flat coal surfaces with various surface roughness values. As a probe moved on the surface of coal, the surface roughness readings of coal surface were recorded on the work line and the average value was used for analysis. Roughness parameter Ra was obtained and used for representing the flat coal surface properties. Each flat coal surface was measured by three times and the final Ra value was obtained using the arithmetic mean values of roughness values. As shown in Fig. 1, the Ra value decreases with the increase of meshes of sand papers. It indicates the flat coal surface becomes smoother by using higher meshes of sand paper in the polishing treatments.

2.4. Attachment time measurements

The bubble-particle attachment time measurements were conducted with the Attachment Timer (made by University of Alberta, Canada) (Gu et al., 2003).

First, the lump coal was agglutinated to a slide glass in order to ensure the measuring surface is level. It was a required experimental condition for the Attachment Timer. Then, the lump coal was transferred to a small cell filled with distilled water. The immersed coal were remained in the water-filled cell for >30 min and the wash bottle was used to produce a jet flow to clean the micro-bubbles on flat coal surface and the entrapped air at the rougher surfaces were significantly removed. As shown in Fig. 2, the flat coal surface (with surface roughness of about 1.6 μm) has many micro-bubbles when it is immersed in the water. These micro-bubbles are significantly removed after the surface

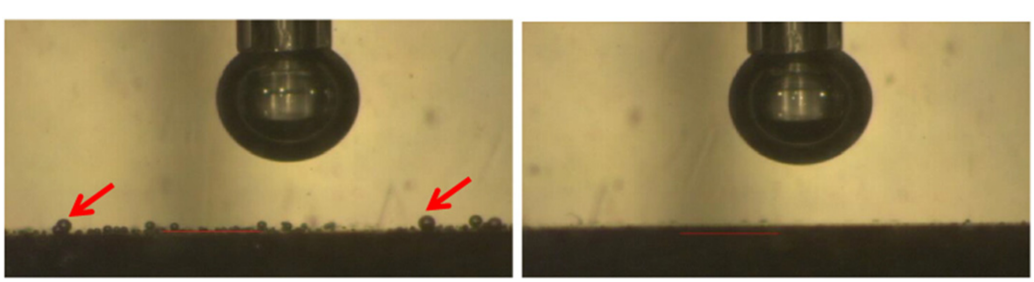

Fig. 2. Immersed coal surfaces before and after jet flow cleaning.