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Dispersion of kaolin powders in silica sols

Zhi Zhang [a,b], Xuchen Lu [a,*], Peng Su [c]

[a] State Key Laboratory of Multiphase Complex System, Institute of Process Engineering, Chinese Academy of Sciences, Beijing 100190, PR China
[b] Graduate University of Chinese Academy of Sciences, Beijing 100049, PR China
[c] Baoto Aluminum (group) Co. Ltd. Baoto 014000, PR China

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ABSTRACT

The dispersion properties of kaolin powders in silica sols were investigated by electrokinetic, viscosity and rheological measurements. Silica sol improved the dispersion of kaolin powders by increasing the negative charges on kaolinite particles. Electrophoretic mobility and viscosity of the kaolin particles in silica sol changed significantly in comparison with dispersions in deionized water. The kaolinite particles in silica sol showed a maximum of the electrophoretic mobility and a minimum in viscosity around pH 11.5. The viscosity of the dispersion reached a minimum when the silica sol concentration was 5 mass%. The flow behavior was non-Newtonian showing shear-thinning. When the solid content exceeded 45 mass%, the dispersion showed pronounced thixotropic behavior.

1. Introduction

Colloidal processing has received considerable interest in the production of high performance ceramics. The primary objective of this processing is to obtain homogeneous ceramic slurries with high stability because the microstructure of the green bodies is greatly influenced by the rheological properties of the ceramic slurries (Kelso and Ferrazzoli, 1989; Briscoe et al., 1998; Lewis, 2000). However, fine ceramic particles coagulate spontaneously in deionized water. Dispersants are used to improve the dispersion of ceramic particles.

Dispersants improve the dispersion of ceramic powders by adsorption. Organic dispersants like polyelectrolytes are often selected as dispersants which stabilize by electrostatic and steric stabilization. Recently, dispersion of ceramic powders with inorganic sols was reported. Zirconium hydrogel was used to improve the dispersion of slip casting zirconia (Petroff et al., 1993, 1995). Yang and Troczynskl chose alumina sol as the dispersant of alumina and silicon carbide powders (Yang and Troczynskl, 1999). A silica sol was selected to disperse alumina and talc powders (Zhu et al., 2001; Yao et al., 2005). It was proposed that the dispersion and stabilization of alumina and talc particles in the silica sol are attributed to the adsorption of the colloidal particles. Inorganic sols are considered as efficient and also clean dispersants for ceramic powders because they cannot only provide high bonding strength of green bodies due to its conversion to a solid gel at relatively low temperature, but also improve the sinterability of ceramic powders (Iler, 1979; Brockmeyer and Dore, 1989). Unlike organic dispersants which will sublimate or burn out during the sintering process, the silica particles can be sintered with the ceramic powders, which will reduce the micro-defects of the ceramic product.

In this paper, the dispersion properties of kaolin powders in silica sol are studied. The influence of pH, silica sol concentration, and solid content on dispersion behavior of the kaolin dispersion was investigated in order to fabricate mullite–cordierite porous ceramics.

2. Materials and methods

Commercial kaolin ($d_{50}=3$ μm, $D=2.6$ g/cm^3, Inner Mongolia, China) was used in this study. The shape of the kaolinite particles was observed by scanning electron microscopy (SEM) (JSM 6700F, Japan) (Fig. 1). The particle size distribution of the silica sol particles (30 mass%, pH = 9–9.5, Beijing Hongxin, China) was measured by a laser scattering method (LS13320, USA). Granulometric distribution was monomodal with a maximum at 29.3 nm (Fig. 2).

The electrophoretic mobility of the kaolinite powders dispersed in deionized water and silica sol, as a function of pH, was measured with JS94H Micro-Electrophoretic Instrument (Shanghai Zhongchen Company, China). The pH of the diluted dispersions (0.05 mass%) was adjusted with 1 N HCl and 1 N NaOH.

Aqueous kaolin dispersions were prepared by ball milling with alumina balls. Viscosity and rheological behavior measurements were carried out on a DV-II+ Pro Viscometer (BROOKFIELD, USA). All measurements were performed at 26 °C with a temperature controller.

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* Corresponding author. Tel.: +86 10 62562448; fax: +86 10 62561822.
E-mail address: xclu@home.ipe.ac.cn (X. Lu).

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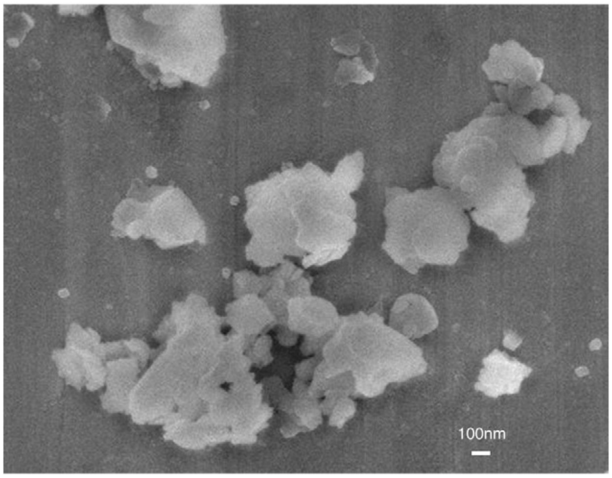

Fig. 1. SEM micrograph of kaolinite particles.

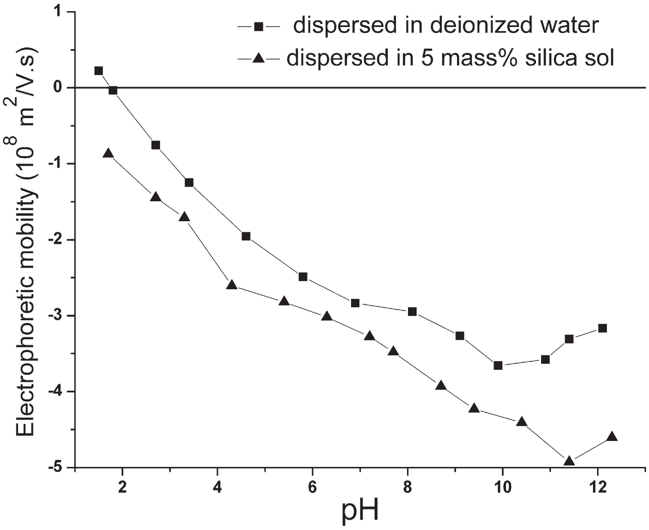

Fig. 3. Electrophoretic mobility of the kaolinite particles as a function of pH.

3. Results and discussion

3.1. Electrophoretic mobility

The electrophoretic mobility of the kaolinite particles dispersed in deionized water and in 5 mass% silica sol at different pH is shown in Fig. 3. The iep (isoelectric point) of the kaolinite particles in deionized water was about pH 2. The electrophoretic mobility was negative in the pH range 2–13 and reached a minimum negative value at pH 10. These results are in agreement with that reported by Yao (2005). The iep of the kaolinite particles in silica sol was estimated to be around pH 0.7 by extrapolation. The absolute value of electrophoretic mobility of the kaolinite particles in the silica sol was higher than in deionized water which demonstrated that silica sol can improve the dispersion of kaolinite particles. This is attributed to the adsorption of negatively charged silica particles on the kaolinite particles (Zhu et al., 2001) as evidenced from Fig. 4. The maximum mobility of the kaolinite particles in the silica sol indicates that the adsorption of colloidal particles on the kaolinite reaches a limiting value. A further increase of pH value only increases the ion strength in the dispersion and reduces the potential difference between the surface of particle and bulk phase, and consequently slightly decreases the absolute value of the electrophoretic mobility.

3.2. Rheological behavior

3.2.1. Effect of pH

The viscosity of the kaolin dispersions in deionized water and in 5 mass% silica sol as a function of pH is plotted in Fig. 5. The viscosity of the dispersions decreased as pH increased and reached a minimum at pH 10 and pH 11.5 respectively. The viscosity of the silica sol kaolin dispersion was lower than in deionized water, indicating a higher degree of dispersion.

The basal planes of the kaolinite particles are negatively charged independent of pH. The edge charge created by the dissociation of silanol and aluminol groups changes from positive at low pH to negative at higher pH (Lagaly, 1989; Benna, 1999; Johnson et al., 2000). At low pH, the positively charged edges of kaolinite particles and their negatively charged basal faces can form edge(+)/face(−) contacts (card-house structure) (Olphen, 1977; Lagaly, 1989, 2006). At higher pH, both the edges and basal faces are negatively charged, and they can form the face(−)/face(−) contacts (band-like structure) in the presence of salts and decrease the viscosity of the dispersion (Lagaly, 1989; Luckham and Rossi, 1999; Lagaly, 2006).

3.2.2. Effect of silica sol concentration

The silica sol concentration had a significant effect on the dispersion of kaolin powders (Fig. 6). The viscosity of kaolin dispersion decreased as the silica sol concentration increased and reached a minimum value at a silica sol concentration of 5 mass% indicating that the adsorption of colloidal silica particles on the kaolinite particles was saturated. At higher silica sol concentration, the silica particles formed a network which increased the viscosity slightly (Yao, 2005). As shown in Fig. 7, the dispersions showed shear-thinning behavior at all silica sol concentrations. The minimum of viscosity was found at

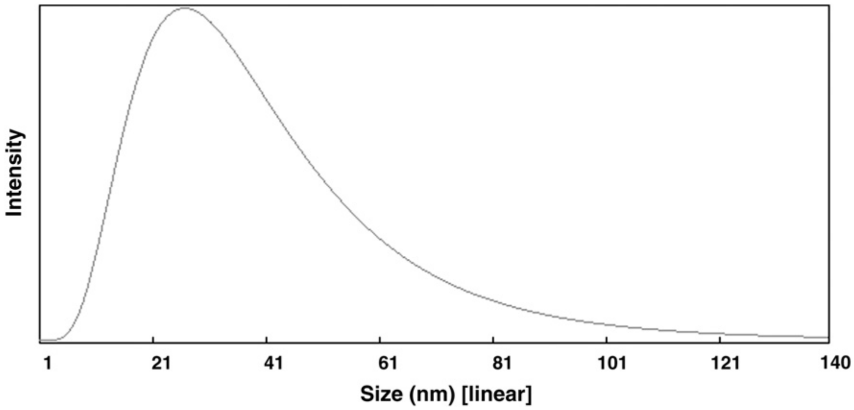

Fig. 2. Particle size distribution of silica sol particles.