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Transactions of Nonferrous Metals Society of China

www.tnmsc.cn



Trans. Nonferrous Met. Soc. China 28(2018) 2125–2134

Effect of ammonium chloride on leaching behavior of alkaline anion and sodium ion in bauxite residue

Yi-wei LI¹, Jun JIANG^{1,2}, Sheng-guo XUE^{1,2}, Graeme J. MILLAR³, Xiang-feng KONG¹, Xiao-fei LI¹, Meng LI¹, Chu-xuan LI¹

 School of Metallurgy and Environment, Central South University, Changsha 410083, China;
 Chinese National Engineering Research Center for Control & Treatment of Heavy Metal Pollution, Central South University, Changsha 410083, China;
 Institute for Future Environments, Science and Engineering Faculty, Queensland University of Technology (QUT), Brisbane Qld 4000, Australia

Received 29 January 2018; accepted 23 May 2018

Abstract: This study focused on leaching behavior of alkaline anion and sodium in bauxite residue through ammonium chloride treatment. The results showed that the pH of bauxite residue decreased from 10.49 to 8.93, total alkaline anion (HCO_3^-, CO_3^{2-}, OH^- , AIO_2^-) concentration reduced from 38.89 to 25.50 mmol/L, leaching rate of soluble sodium was 80.86% with ammonium chloride addition of 0.75%, liquid/solid (L/S) ratio of 3 (mL/g), temperature of 30 °C and reaction time of 18 h; L/S ratio was the main factor affecting the removal of alkaline anion and the leaching of sodium. Furthermore, ammonium chloride promoted the dissolution of diaspore and changed the micro/morphological characteristics with the increase of massive structure. The findings of this work will contribute to achieve soil-formation of bauxite residue.

Key words: bauxite residue; ammonium chloride; leaching behavior; alkaline regulation; soil formation

1 Introduction

Bauxite residue is an alkaline by-product, derived from the alumina extraction from bauxite via the Bayer process, which involves use of high concentration of caustic liquor (NaOH) under elevated-temperature and high-pressure conditions [1-3]. 1 t alumina generates 0.5-2 t bauxite residue [4,5]. The current global inventory of bauxite residue is more than 4×10^9 t and still grows at a rate of 1.5×10^8 t/a [6,7]. The high alkalinity, pH and salinity of bauxite residue make it difficult to dispose and the actual utilization rate is less than 10% [8]. Therefore, bauxite residue is majorly deposited in storage reservoirs, which not only requires substantial land area but also contaminates the surrounding environment [9]. Moreover, there was the potential for catastrophic dam breakage that occurred in bauxite residue yard of the Hungarian Ajkai Timfoldgyar Alumina Plant in 2010. This disaster engulfed three

villages located downstream of the plant [10]. In recent years, Guizhou, Guangxi, Shandong, Shanxi, Henan and other provinces in China reported that bauxite residue contaminated groundwater and surface water, thus causing potential threats to the environment [11].

The physical, chemical and mineralogical properties of bauxite residue vary due to the difference of raw ore source and refining process [12]. Generally, bauxite residue has a pH in the range of 10-13 and leachate from bauxite residue disposal areas (BRDAs) has pH values of 12-14 [13,14]. The alkaline substances in bauxite residue are generally divided into two categories: the first comprises soluble alkaline substances containing residual NaOH, sodium carbonate, sodium bicarbonate and sodium aluminate; the second comprises insoluble alkaline substances of the bauxite residue minerals, such as sodalite, cancrinite, calcite and other mineral components [15,16]. Generally, soluble alkaline substances and insoluble alkaline substances can be transformed during the long-term natural storage of

Foundation item: Projects (41877511, 41842020) supported by the National Natural Science Foundation of China; Project (201509048) supported by the Environmental Protection's Special Scientific Research for Chinese Public Welfare Industry

Corresponding author: Sheng-guo XUE; Tel: +86-13787148441; E-mail: sgxue70@hotmail.com; sgxue@csu.edu.cn DOI: 10.1016/S1003-6326(18)64857-5

bauxite residue [8,17]. Recently, the research on bauxite residue has mainly focused on alkalinity regulation by seawater, gypsum, inorganic acid, acid gas, brine, water leaching and biological method [18-20]. The mechanism for seawater and brine neutralization of bauxite residue is through reactions of Ca²⁺ and Mg²⁺ with alkaline anions, to form chemical bonded alkali, thereby reducing pH, promoting the dissolution of sodium and improving its physico-chemical structure. However, the method requires the plant located close to the coast [21,22]; alternatively, gypsum can release Ca²⁺, forming calcite precipitates with alkaline ions, which suppresses the solubility of solid phase alkalinity and ultimately reduces the pH and aluminum ion concentration. Nevertheless, the method would take a long-time to realize revegetation [23,24]. Acid neutralization can remove most of free alkali and even dissolve calcium and aluminum ions; however, pH readily reverts to the initial level, valuable metals may dissolve and secondary pollution may occur [17]. Acidic gases such as CO₂ can react with hydroxide species to form carbonate and bicarbonate, which affects the dissolution of other chemical bonded alkali materials. Nevertheless, acid gas neutralization is challenging to operate because of various practical limitations [25,26]. Water leaching process is mainly used for alkali recycle, but its dealkalization rate is less than 50% and a large volume of water is required [27,28]. Biological methods mainly focus on the screening of acidogenic microorganisms which can produce acid. These methods can not only potentially improve the physicochemical properties of bauxite residue, but also reduce the alkalinity and pH. Nevertheless, high alkalinity is known to limit the development of bacteria species and quantities [29]. Salt leaching method mainly refers to inorganic salt or acidic solutions as leaching agents to dissolve Na2O and other useful ingredients in bauxite residue, such as $Fe_2(SO_4)_3$, Al₂(SO₄)₃, MgCl₂ and CaCl₂ [30]. It was reported that the content of Na2O in insoluble residue could be reduced to less than 1% under optimized experimental conditions with reaction temperature of 160 °C, reaction time of 4 h, ammonium chloride addition of 1.5 times theoretical dosage and bauxite residue particle size of 94-150 µm [31]. As leaching agent was used to extract sodium in bauxite residue, the leaching rate of sodium ion by ammonium chloride treatment was the same as that of multiple washing by water, but the dosage of ammonium chloride was five times higher than bauxite residue [32].

Ammonium chloride as a leaching agent for bauxite residue is particularly of interest and the design of an optimal ammonium chloride dosing strategy could effectively regulate alkalinity in bauxite residue. So, the present investigation aimed at elucidating the effects of ammonium chloride on: (1) the changes of alkaline anion and sodium in bauxite residue; (2) the optimal experimental condition by combining single factor experiments with orthogonal experiment; (3) changes in mineral composition and morphology. The methodology involved addition of ammonium chloride to bauxite residue at bench scale. Future directions for regulating alkalinity of bauxite residue prior to disposal have been provided, which are potentially of great significance to the alumina refining industry.

2 Experimental

2.1 Materials

Raw bauxite residue was collected from the bauxite residue disposal areas (BRDAs) in Guangxi Pingguo Aluminum Refinery, China. Bauxite residue sample was air-dried, ground, sieved (150 μ m), and finally oven-dried at 65 °C for 48 h. Ammonium chloride was dried at 50 °C in an oven for 4 h. All of reagents used in the experiment were analytical grade. The main cation concentrations from dissolution of soluble alkali in bauxite residue are presented in Table 1.

 Table 1 Main cation concentrations from dissolution of soluble alkali in bauxite residue (mg/L)

Na	Al	Κ	Ca
1198.00	67.50	86.70	2.73

2.2 Methods

Three experiments were performed as follows. A single factor experiment was conducted to investigate the effects of ammonium chloride addition, L/S ratio, leaching temperature and leaching time on the leaching behavior of alkaline anion and sodium. The addition amount of ammonium chloride was set at mass fractions of 0, 0.25%, 0.50%, 0.75%, 1.00%, 1.25% and 1.50%; the L/S ratio was set to be 1, 2, 3, 4, 5, 6 and 7, leaching temperature was controlled to be 10, 15, 20, 25, 30, 35 and 40 °C, and leaching time was controlled to be 0.5, 1, 1.5, 2, 4, 6, 9, 12, 18, 24 and 30 h. The leaching behavior of alkaline anion and sodium was analyzed, while the appropriate conditions for alkaline regulation and sodium leaching were selected for the following experiments. For the second experiment, orthogonal experiment of three factors and three levels was designed to identify the optimal conditions for alkaline regulation and sodium leaching. For the final experiment, the effects of ammonium chloride addition on the solid phase and surface properties of bauxite residue were analyzed by X-rav diffractometry (XRD), scanning electron microscopy (SEM) and energy dispersive spectrometer (EDS). 20 g of treated bauxite residue sample was mixed with a certain amount of ammonium chloride and deionized water in a beaker, stirred vigorously with a glass rod for 30 s, and finally the breaker was sealed with film and placed at water bath with constant temperature. The leaching solution was filtered through a SHZ-D (III) vacuum suction filter. Afterwards, the pH of leaching solution was measured by a PHS-3C pH meter and the OH⁻ concentration in solution was calculated by pH data. The concentrations of CO_3^{2-} and HCO_3^{-} were determined by double- indicators neutralization titration using phenolphthalein and bromophenol blue as indicators and 0.005 mol/L H₂SO₄ as a titrant; the ammonium ion concentration (measured as "N") of the leaching solution was determined by Nessler's reagent spectrophotometry [33]. The chloride ion concentration in the leaching solution was determined by UV-Vis spectrophotometry and the concentration of sodium ion in leaching solution was determined by a flame atomic spectrophotometer [34].

3 Results and discussion

3.1 Effect of ammonium chloride addition

The effects of ammonium chloride addition on pH, alkaline anions and sodium ion leaching characteristics of bauxite residue are shown in Figs. 1 and 2 (L/S ratio 3, temperature 25 °C, and reaction time 6 h). Increasing addition of ammonium chloride resulted in a significant reduction in the pH of bauxite residue. A relatively rapid pH decrease in the leaching solution from 10.39 to 8.84 was observed when the ammonium chloride addition was raised from 0 to 0.75%. After this point, the change in pH was comparatively slow and appeared to tend towards a final value of 8.60. The pH of bauxite residue didn't change significantly after 0.75% of ammonium chloride addition potentially due to the buffering effect of carbonate and bicarbonate species. Referring to ammonium chloride addition, the main chemical reactions in the bauxite residue are illustrated in Eqs. (1)–(5) [31]:

$$Na_2CO_3 + 2NH_4Cl = 2NaCl + 2NH_3\uparrow + H_2O + CO_2\uparrow$$
(1)

$$NaHCO_3 + NH_4Cl = NaCl + NH_3 \uparrow + H_2O + CO_2 \uparrow$$
(2)

$$Na_2O+2NH_4Cl=2NaCl+2NH_3\uparrow+H_2O$$
(3)

$$NaOH+NH_4Cl=NaCl+NH_3\uparrow+H_2O$$
(4)

$$Al_2O_3 + 6NH_4Cl = 2AlCl_3 + 6NH_3 \uparrow + 3H_2O$$
(5)

)

There exists a double-hydrolysis reaction between ammonium chloride and carbonate [35,36]:

$$NH_4^+ + H_2O \longrightarrow NH_3 \cdot H_2O + H^+$$
(6)

$$\operatorname{CO}_3^{2-} + \operatorname{H}_2 \operatorname{O} \Longrightarrow \operatorname{HCO}_3^{-} + \operatorname{OH}^{-}$$

$$\tag{7}$$

$$HCO_3^-+H_2O \rightarrow H_2CO_3^+OH^-$$
 (Incomplete hydrolysis) (8)



Fig. 1 Effect of ammonium chloride (AC) addition on pH and alkaline anion concentration (Total = $CO_3^{2-} + HCO_3^{-} + AlO_2^{-} + OH^{-}$)



Fig. 2 Effect of AC addition on concentration of sodium ion and AC consumption concentration

With ammonium chloride addition increasing, the carbonate concentration was markedly decreased (Fig. 1). As the pH of the solution maintained above 8.60 throughout the experiment, it was inferred that the reduction in carbonate concentration was not simply due to transformation of carbonate to bicarbonate (Eq. (7)). This assumption was supported by the fact that slight increase in bicarbonate concentration was not sufficient to account for all the carbonate removed from solution. Instead, it was proposed that the reaction between ammonium chloride and carbonate leached from the bauxite residue resulted in carbonate consumption (Eq. (1)). When the ammonium chloride addition reached 1.50%, the carbonate was completely consumed.

The sodium ion concentration in the leachate increased as a result of ammonium chloride addition, and a positive correlation was observed within the specific ranges of 0-0.50% and 1.00%-1.50% addition of ammonium chloride (Fig. 2), indicating that ammonium chloride addition promoted the leaching rate of sodium ion in bauxite residue markedly. In contrast, the

concentration of sodium ion exhibited a slight downward/plateau trend in the ammonium chloride range of 0.50%–0.75% (Fig. 2). The reason might be the double-hydrolysis reaction between carbonate and ammonium ion of the dominant role, resulting in the consumption of ammonium ion and inhibiting the promotion of sodium ion leaching by ammonium ion. The consumption of ammonium ion increased slightly at ammonium chloride addition of 1.00%, because the large consumption of carbonates resulted in only a little amount of alkaline anion that reacted with ammonium.

The consumption of chloride ions introduced by ammonium chloride addition was negligible (Table 2). Considering the impact of experimental error and other aspects, it could be concluded that chloride ion did not participate in any reactions and essentially remained in the leaching solution and the main contribution to sodium ion leaching was the extraction ability of ammonium ion.

3.2 Effect of L/S ratio

The effects of L/S ratio (mg/L) on pH, alkaline anion and sodium ion leaching characteristics of bauxite residue are shown in Figs. 3 and 4 (ammonium chloride

Table 2 Effect of AC addition on chloride ion consumption					
AC addition/g	Consumption of chloride ion/(mg \cdot L ⁻¹)				
0	9.10±2.37				
0.05	18.00±5.59				
0.10	8.70±3.58				
0.15	7.56±1.85				
0.20	10.31±3.25				
0.25	13.04±5.90				
0.30	9.93±3.36				

addition 0.75%, temperature 25 °C, and reaction time 6 h). The pH of bauxite residue leachate and the primary alkaline anion concentrations varied with increasing L/S ratio (Fig. 3(a)). The ammonium ion and alkaline anion in the leaching solution were simultaneously diluted as the L/S ratio increased. When the L/S ratios were 1, 2, 3 and 4, the roles of water dilution and ammonium ions double-hydrolysis together maintained stable pH. When the L/S ratio was more than 5, the reduced ammonium ion concentration was not conducive to the reaction of ammonium ions with alkaline anion in bauxite residue. Therefore, the pH gradually increased, but not



Fig. 3 Effects of L/S ratio on pH, alkaline anion concentration (a) and alkaline anion amount (b)



Fig. 4 Effects of L/S ratio on sodium ion leaching and AC consumption: (a) Concentration; (b) Amount

significant. This observation was probably due to the buffering effects of carbonate, bicarbonate and ammonium ions in the solution. The leaching of carbonate was notably impacted by ammonium ion concentration, and the carbonate concentration gradually increased when the L/S ratio was more than 3. The double-hydrolysis reaction between carbonate and ammonium ions was weakened, which resulted in transformation of bicarbonate to carbonate (evidenced by the downward trend in bicarbonate concentration). The concentrations of bicarbonate and carbonate were relatively stable when L/S ratio was 5 or above. As the concentration characterization of L/S ratio was not comprehensive, the total amount of leaching ions was used for joint characterization (Fig. 3(b)). The change in the total amount of leached alkaline anion was consistent with the change in concentration, proving the previous analysis.

The change trends of sodium ion leaching concentration and ammonium ion consumption were closely related (Fig. 4). When L/S ratios were 1 and 2, the reactions between ammonium ion and alkaline anion were stronger, leading to large ammonium ion consumption. Ion-exchange happened between ammonium ion and sodium ion adsorbed on bauxite residue surface, which promoted the dissolution of soluble sodium. The leaching amount reached the maximum of 53.36 mg and the sodium ion leaching concentration was 889.34 mg/L when L/S ratio was 3.

As for pH, concentration and amount of alkaline anion and sodium ion, L/S ratios of 1, 3 and 5 were selected as the key influence points of L/S ratio. Moreover, when L/S ratio was 3, the pH and concentration of alkaline anion were low, and the amount of sodium leaching reached the maximum. Therefore, the following single-factor experiment may be conducted at L/S ratio of 3, and L/S ratios of 1, 3 and 5 may be considered as orthogonal experimental conditions.

3.3 Effect of leaching temperature

The effects of leaching temperature on pH, alkaline anion and sodium ion leaching characteristics of bauxite residue are shown in Fig. 5 (ammonium chloride addition 0.75%, L/S ratio 3, and reaction time 6 h). The pH of bauxite residue leachate and the primary alkaline anion concentration varied with increasing leaching temperature (Fig. 5). The pH showed an upward tendency after 30 °C and became stable finally, which was potentially due to elevated temperature promoting the dissolution of chemical bonded alkali in bauxite residue. Moreover, leaching temperature rise was not conducive to the double-hydrolysis between ammonium ion and carbonate, bicarbonate, and the ion exchange between ammonium ion and sodium ion adsorbed on bauxite residue surface was suppressed, so pH presented an upward trend. At 30 °C, bicarbonate concentration reached the minimum value while carbonate concentration increased. Above 35 °C, carbonate slightly increased and bicarbonate slightly decreased (although still similar in magnitude to values at lower temperatures). Hydrolysis reactions described in Eqs. (7) and (8) were inhibited with the increase of temperature, thus the transformation between bicarbonate and carbonate was dominant, which led to a negative correlation between bicarbonate and carbonate. However, the variation of total alkaline anion concentration was small, mainly due to the fact that leaching temperature did not have a substantial impact upon the double-hydrolysis between ammonium ion and carbonate, but rather the conversion between carbonate and bicarbonate played a dominant role.



Fig. 5 Effects of leaching temperature on pH and alkaline anion concentration

The concentrations of sodium and ammonium ions initially increased and then decreased with an increase of leaching temperature, and the trend was consistent (Fig. 6). Above 30 °C, sodium ion leaching concentration showed a decreasing trend while ammonium ion consumption concentration reached the maximum value at 25 °C. Moreover, it was inferred that at a temperature above 30 °C, ion exchange between sodium and ammonium ions was inhibited, potentially due to the elevated pH converting ammonium ions to ammonia gas. Considering the key points affected by leaching temperature, 25, 30 and 35 °C were selected as orthogonal experimental conditions, and 30 °C was selected as the optimum condition for single factor experiment.

3.4 Effect of leaching time

The effects of leaching time on the pH, alkaline anion concentration and sodium ion leaching characteristics of bauxite residue are shown in Fig. 7



Fig. 6 Effects of leaching temperature on sodium ion concentration and AC consumption concentration



Fig. 7 Effects of leaching time on pH and alkaline anion concentration

(ammonium chloride addition 0.75%, L/S ratio 3, and temperature 30 °C). The pH of bauxite residue leachate and the primary alkaline anion concentration varied with increasing leaching time. The pH of bauxite residue leaching solution remained stable at 0-6 h, and then increased gradually at 6-18 h. The ammonium ions and the carbonate were double-hydrolyzed after ammonium chloride was added at the beginning of 6 h, and the neutralization between hydroxide ion produced by hydrolysis promoted the double-hydrolysis, which led to the equilibrium relationship between chemical bonded alkali and soluble alkali. After 6 h, pH gradually increased with the conversion of chemical bonded alkali to soluble alkali until a new chemical equilibrium relationship was reached among ammonium, carbonate, and chemical bicarbonate bonded alkali. The double-hydrolysis between ammonium ion and carbonate occurred after the addition of ammonium, which consumed a lot of carbonate and broke the equilibrium relationship between carbonate and bicarbonate with bicarbonate gradually converting to carbonate.

The variation trend between ammonium ion consumption concentration and sodium ion leaching concentration was similar (Fig. 8). Both sodium ion leaching concentration and ammonium ion consumption concentration increased firstly and then became stable, mainly resulting from ion exchange reaction between sodium and ammonium ions, which required a certain reaction time. When the leaching time was 6 h, sodium ion concentration reached a maximum of 924.89 mg/L (Fig. 8). Again, the elevated pH after 6 h may have suppressed ion exchange process due to the formation of more ammonia.

Considering the key points of above experiments, 4, 6 and 18 h were chosen as orthogonal experimental conditions, and 18 h could be used as optimum condition of single factor experiment.



Fig. 8 Effects of leaching time on sodium ion leaching concentration and AC consumption concentration

3.5 Orthogonal experimental analysis for optimized regulating conditions

Orthogonal experiment was used to identify the dominant factors and optimized conditions for regulating alkalinity of bauxite residue. Factors and levels based on single factor experiments and the results of orthogonal experiment are summarized in Tables 3 and 4, respectively. The conditions of L/S ratio 3, temperature 30 °C, and reaction time 18 h were adopted to regulate alkalinity of bauxite residue. Under optimal experimental conditions, pH decreased to 8.93, total alkaline anion concentration decreased from 38.89 to 25.50 mmol/L and leaching rate of soluble sodium reached 80.86%.

The data indicated that L/S ratio was the main factor affecting pH, alkaline anion and sodium ion leaching, which was presumably due to the concentration of ammonium ions associated with L/S ratio affecting the reaction efficiency. Leaching time was determined as the secondary factor on pH and alkaline anion due to the rapid initial reaction rate between soluble alkaline substances and ammonium ions. However, the dissolution of insoluble alkaline substances eventually formed the hydrolysis equilibrium between ammonium ion and alkaline anion as leaching time increased. The effect of temperature on ion exchange reaction between sodium and ammonium ions was significant so that leaching temperature for sodium leaching was the secondary factor.

Table 3 Factors and levels of orthogonal experiments at residue mass of 20 g and ammonium chloride mass of 0.15 g

			0
Level	L/S ratio	Temperature/°C	Time/h
1	1	25	4
2	3	30	6
3	5	35	18

Table 4 Results of orthogonal experiments							
No.	L/S ratio	T∕°C	<i>t</i> /h	pН	W_1 /mmol	W_2/mg	
1	2	25	4	8.90	0.89	49.22	
2	2	30	6	8.93	0.79	54.23	
3	2	35	18	9.03	1.16	53.35	
4	3	25	6	8.81	1.31	54.92	
5	3	30	18	8.93	1.53	58.12	
6	3	35	4	8.89	1.12	55.58	
7	5	25	18	9.13	2.34	48.31	
8	5	30	4	8.99	1.63	52.90	
9	5	35	6	9.04	2.08	42.41	
Ι	8.95	8.95	8.92				
II	8.88	8.95	8.92				
III	9.05	8.99	9.03				
R_1	0.18	0.04	0.10				
Ι	0.95	1.51	1.21				
II	1.32	1.32	1.39				
III	2.02	1.45	1.68				
R_2	1.07	0.20	0.46				
Ι	52.27	50.82	52.56				
II	56.21	55.08	50.52				
III	47.87	50.45	53.26				
R.	8 33	1.64	2 74				

T is temperature; *t* is time; W_1 is total alkaline anion amount; W_2 is sodium ion leaching amount, *R* is range

3.6 Mineral and morphology characteristics

The solid-phase mineral compositions of bauxite residue treated by different ammonium chloride amounts were characterized by XRD (Fig. 9). The results showed that the main mineral components in bauxite residue were andradite, gibbsite, calcite, cancrinite, diaspore, grossular and hematite. Ammonium chloride exhibited negligible effect on the solid-phase composition of bauxite residue. However, when the diffraction angle (2θ) was about 57° at the arrow mark in the figure, the addition amount of ammonium chloride was 0, the peak of diaspore was weakened, and the peak of diaspore was weaker when the ammonium chloride addition was 0.75%. When the diffraction angle (2θ) was 69°, the peak of diaspore also performed the same law, furthermore, the peak of diaspore in bauxite residue treated by ammonium chloride disappeared. The XRD patterns of bauxite residue by different treatments showed that the addition of ammonium chloride had little effect on the solid phase composition of bauxite residue, but had a positive effect on the dissolution of diaspore in solid phase.



Fig. 9 XRD patterns of bauxite residue by different treatments (BR: Bauxite residue; AC0: Without addition of ammonium chloride; AC0.75: Addition of 0.75% ammonium chloride; AC1.5: Addition of 1.50% ammonium chloride)

SEM images and EDS results of bauxite residue treated by different ammonium chloride amounts are shown in Fig. 10. The microstructure of bauxite residue with only water leaching was loose and contained fine particulate matter and debris. With the increase of ammonium chloride addition, the fine particles and debris gradually reduced in quantity, and large agglomerates gradually increased. The results indicated that the sodium ions adsorbed in bauxite residue were released into the liquid phase by ion exchange between sodium and ammonium ions, which changed the surface properties of bauxite residue and promoted the surface cementing among the bauxite residue particles. Moreover, the addition of ammonium ions favored the adhesion of bauxite residue particles and promoted the formation of large aggregates [37,38]. Analysis by EDS of the elemental composition and relative content of bauxite residue surface was also completed (Fig. 10). The content of sodium decreased from 3.91% to 1.62% when ammonium chloride addition was raised from 0 to 0.75%. These data indicated that the sodium ions adsorbed in



Fig. 10 SEM images (a_1-d_1) and EDS results (a_2-d_2) of bauxite residue with different treatments: (a_1, a_2) Bauxite residue; (b_1, b_2) AC0; (c_1, c_2) AC0.75; (d_1, d_2) AC1.5

bauxite residue were possibly released into the liquid phase by ion exchange between sodium and ammonium ions. There is the potential for the resultant changed surface properties of bauxite residue to promote surface cementing among the bauxite residue particles as evidenced in the SEM images. Simultaneously, the content of aluminum on the bauxite residue surface was reduced from 15.63% to 4.74% when the ammonium chloride addition was raised from 0 to 0.75%, mainly due to the reaction between ammonium ion and alumina species (Eq. (5)) which promoted the dissolution of aluminum oxide.

XRD, SEM, EDS, single factor experiment and orthogonal experiments have revealed that mechanisms of regulating bauxite residue alkalinity were mainly manifested in two aspects. On the one hand, the double-hydrolysis of ammonium ion with alkaline anion consumed a substantial amount of alkaline anions, decreasing the critical anion concentration and pH. Furthermore, the ion-exchange between ammonium and sodium ions on the surface of bauxite residue generated a potential alkalinity regulation of bauxite residue by promoting the dissolution of sodium.

4 Conclusions

1) Optimal conditions for ammonium chloride treatment were obtained as follows: ammonium chloride addition 0.75%, L/S ratio 3, leaching temperature 30 °C and reaction time 18 h. The pH decreased from 10.49 to 8.93, total alkaline anion concentration reduced from 38.89 to 25.50 mmol/L and leaching rate of soluble sodium was 80.86%.

2) According to the deviation analysis of orthogonal experiment, L/S ratio was the main factor affecting the removal of alkaline anion and the leaching of sodium ions.

3) Ammonium chloride promoted the dissolution of diaspore, changed the micro and morphological characteristics of bauxite residue with the increase of massive structure and the reduction of Na and Al contents on the surface of bauxite residue.

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氯化铵对赤泥碱性阴离子及钠离子浸出行为的影响

李义伟¹, 江 钧^{1,2}, 薛生国^{1,2}, Graeme J. MILLAR³, 孔祥峰¹, 李晓飞¹, 李 萌¹, 李楚璇¹

1. 中南大学 冶金与环境学院,长沙 410083;

2. 中南大学 国家重金属污染防治工程技术研究中心, 长沙 410083;

3. Institute for Future Environments, Science and Engineering Faculty,

Queensland University of Technology (QUT), Brisbane Qld 4000, Australia

摘 要:研究氯化铵处理对赤泥碱性阴离子及钠离子浸出行为的影响。结果表明:在氯化铵添加量为 0.75%、液固比为 3、温度为 30 ℃、浸出时间为 18 h 的条件下,赤泥 pH 从 10.49 降至 8.93,碱性阴离子(HCO₃⁻,CO₃²⁻,OH, AlO₂⁻)浓度从 38.89 降至 25.50 mmol/L,可溶性钠浸出率为 80.86%;液固比是影响碱性阴离子和钠离子浸出的主要因素。氯化铵促进了赤泥中一水铝石的溶解及团粒结构的形成,有助于实现赤泥的土壤化。 关键词:赤泥;氯化铵;浸出行为;碱性调控;土壤化

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