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Full Length Research Paper

Effects of acid leaching aluminum from reservoir bottom sediment soil as a lightweight aggregate matrix

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Three kinds of acid were used to leach bottom sediment soil of water reservoir to diminish aluminum from the soil for preparation of lightweight aggregates. Three concentrations were used in these investigations, including 1, 2 and 5 N. Operating temperatures were set at 25, 50, 70 and 90 celsius. Measuring took place in 1/2, 1, 2, 4 and 8 h. Comparison of before and after leaching, the spectra showed that the mineral composition of chlorite disappeared after acid leaching with a sound effect. Among the three acids, sulfuric acid is the best leaching solution under same operating conditions. The best combination for maximum extraction in this study is 5 N sulfuric acid with temperature set at 90 celsius and 8 h of reaction. We could reach a removal of 3019 ppm aluminum from reservoir bottom sediment soil. This non-aluminum contained soil is great, both in hydration and swelling as a good quality of lightweight aggregate matrix.

Key words: Leach, bottom sediment soil, aluminum, lightweight aggregates, chlorite.

INTRODUCTION

The formation of water reservoir sediments are generally coupled with the natural weathering of geological environments and the crust changes of the earth. Through the movement and sedimentation process, soil particles are softened and scrubbed. Then, the mud flows into the catchment's area and sinks in the reservoir to become sediments (Meral et al., 2010). Some physical and chemical properties of sediments may be different, owing to geological environments, soil composition and sedimentation process in the catchment area (Nascimento and Mozeto, 2008).

In the early days, Taiwan's reservoir sediments were mainly dredged and dried to be used as earthworks backfill for construction purposes. Recently, new methods of investigation have been carried out for reservoir sediments. The most well-known utilization is the preparation of lightweight aggregates (Al-Homoud et al., 1998; Latosińska and Żygadło, 2009). With hard surface, high porosity and low density, lightweight aggregates have several advantages (Ceylan et al., 2005). For example, it is light and sound-proof, and it provides thermal insulation. However, if the percentage of aluminum ion in the chemical composition is high, silica (SiO_2) composition is low (Mosquera, 1990; Koning et al., 2002). In this case, hydration and swelling properties become poor (Steudel et al., 2009). Under such circumstances, it is difficult to prepare good lightweight aggregates. In order to make better lightweight aggregates, the aluminum ion within reservoir sediments needs to be removed as well as possible (Temuujin et al., 2003).

The acid leaching method was originally used to extract gold from gold ore in mineral processing. Some bioleaching methods were also applied to extract heavy metals (Anjum et al., 2009). The purpose of this study is the laboratory investigations on Taiwan Shihmen Reservoir sediment to leach aluminum (Yang et al., 2006) by using three kinds of acid solutions (sulfuric, hydrochloric and nitric acid). With different kinds of acid, normality concentration, operational temperature and reaction time effects can be investigated. Among the operations and outcomes, we select an optimal combination to obtain the best removal of aluminum and prepare a good quality of lightweight aggregate.

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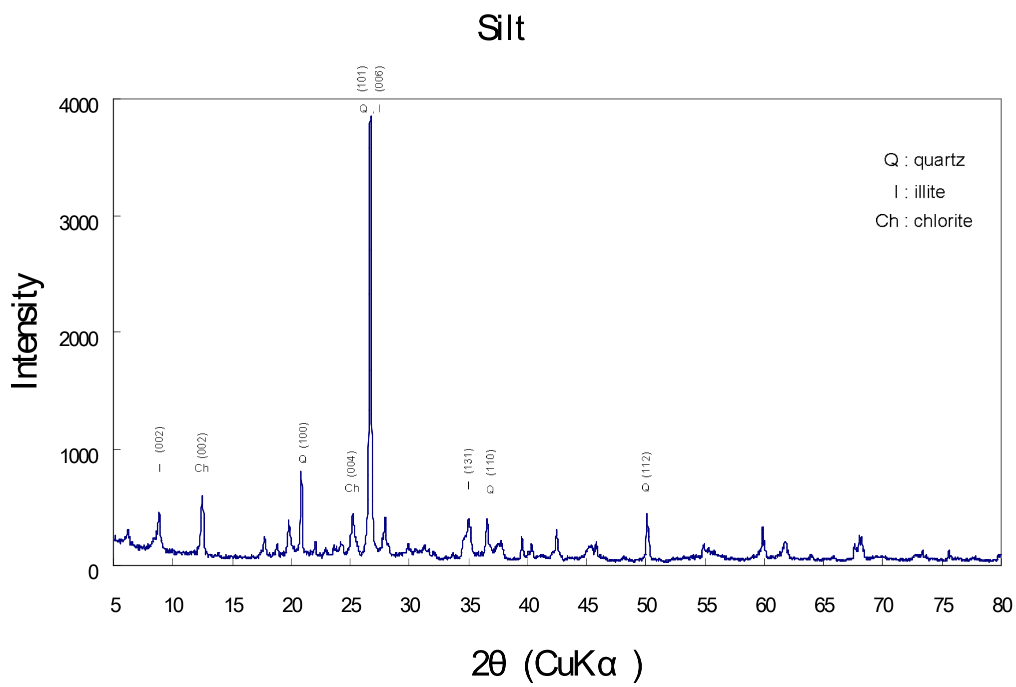

Figure 1. The spectrum of x-ray diffraction for original sediment soil.

MATERIALS AND METHODS

Materials

Sediment soils were collected from Shihmen Water Reservoir, Taoyuan, located in the northern part of Taiwan. Samples first went through a 400 mesh screen. Then, sodium hexametaphosphate and sodium hydroxide were added to adjust the pH = 11. In 20 min of ultrasonic vibration followed by centrifugation, we dumped the upper clear solution. Secondly, we put sodium acetate into the soil to adjust the pH to 5. After an 80°C water bath for 30 min, we dumped the upper clear solution after centrifugation. Then, we put hydrogen peroxide in the solution and heated it up to make the color change from brownish into clear. Again, we added sodium acetate into the soil followed by centrifugation and then, dumped the upper clear solution. Finally, we mixed up tri-sodium citrate dehydrate and natriumdithionit sodium dithionite with soil under an 80°C water bath for 30 min and then, added 2 g of sodium chloride followed by centrifugation. Next, we dumped the upper clear solution until the brownish color disappeared.

Experiment design

Experiments designed originated from leaching process which depends on operational parameters to observe a better aluminum removal (Mendes and Martins, 2003). Acid normality was selected in 1, 2 and 5 N, respectively. Operating temperatures were set at 25, 50, 70 and 90°C. Reaction time was measured from period of 1/2, 1, 2, 4 to 8 h. By observing the stated effects, we can choose the optimal operating conditions for the maximum extraction of aluminum.

Aluminum determination

An x-ray diffraction analyzer (Siemens D-5000, Germany) and ICP-OES ICAP 6000 (Joy Allied Technology Inc.) were the instruments used to analyze the mineral structure and composition of sediment samples. An ultrasonic cleaner (BRANSON 3210-MT, USA) was used for simulation of the acid washing situations. Centrifugation (Hermle Lasortechnik Type Z323K, Germany) was used to separate the soil out of the liquid. An atomic absorption spectrometer (Perkin Elmer AA analyst 100) was used for investigation of the aluminum after acid leaching.

RESULTS AND DISCUSSION

The sediment was obtained from Shihmen Reservoir, Taoyuan, Taiwan and the chemical compositions of the original soil are shown in Table 1. The spectrum of x-ray diffraction for a non-leaching soil sample is presented in Figure 1. The 2nd peak in this spectrum displays the mineral composition of chlorite. After the 5 N concentration of three kinds of acids washing and flushing with temperature settings at 25, 50, 70 and 90°C in this study, we realized that the 2nd peak no longer existed in the spectrum after leaching when the temperature had been heated up to 50°C (or higher). This truly indicates that, the aluminum ion in soil samples was flushed out by the acid solution as shown in Figures 2 to 4.

The function of the acid solution is to wash out the chlorite ore (Arienzo et al., 2001) within the reservoir sediment in a layered silicate with a structure of 2:1:1, as shown in Figure 5. Once the aluminum oriented chlorite ore is nearly removed, the soil is converted into non-aluminum sediment with the silica percentage if the composition goes up. Under such conditions, both hydration and swelling become excellent thanks to the

Table 1. Chemical compositions of reservoir sediment soil

Chemical Compositions Percentage of Shihmen Reservoir Sediment										
items	SiO_2	Al_2O_3	CaO	MgO	SO_3	Fe_2O_3	K_2O	Na_2O	Organic	Total
%	68	19.4	1.4	1.5	0.3	6.5	0.3	0.04	2.3	100

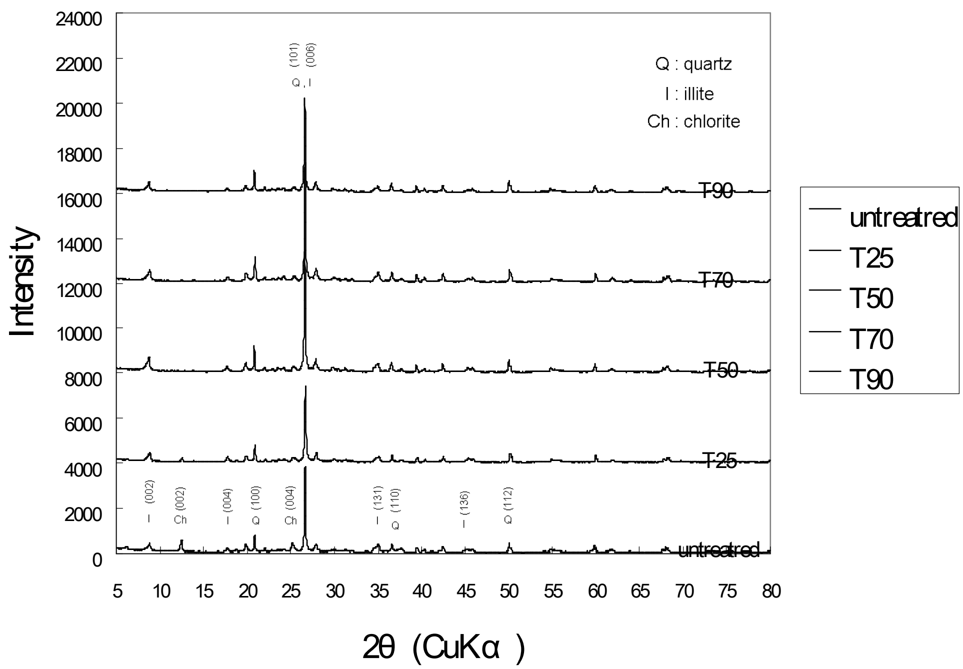

Figure 2. The spectrum of x-ray diffraction for 5N H_2SO_4 sediment soil treatment.

silica. Therefore, it can be prepared as good quality lightweight aggregate.

Effect of acid solutions

1, 2 and 5 N concentrations were selected to extract aluminum in sediment samples during 8 h of reaction for three kinds of acid. The operating temperatures were set at 25, 50, 70 and 90℃. Results of leaching by sulfuric, hydrochloric and nitric acids are presented in Figures 6 to 8, respectively. For the same acid solution, the removal of aluminum from the sediment soil is positively related to the normality concentration and operational temperature. Comparing the three acids in Figures 6 to 8, sulfuric acid shows the best removal efficiency.

Effect of reaction time

Immediately after the acid effect, we investigated the time effect for leaching aluminum by setting the temperature at 90℃ Celsius with 1, 2 and 5 N concentrations. The time effects of three different acids are shown in Figures 9 to 11, respectively. Looking at these Figures, it is obvious that the removal of aluminum from the sediment soil is also positively related to reaction time. This means that, the longer the reaction time, the better the removal efficiency for the same acid solution, normality concentration and operating temperature. Among these three acids, sulfuric acid is the best in regard to time effect.

The maximum extraction

By connecting the effects mentioned earlier, we can choose the optimal operating conditions for the maximum extraction. The best combination to extract aluminum occurs with a concentration of 5 N, a temperature at 90℃ and 8 h of reaction time. Under such operating conditions for the three different acids, we observe that sulfuric acid reaches the maximum removal of aluminum from the

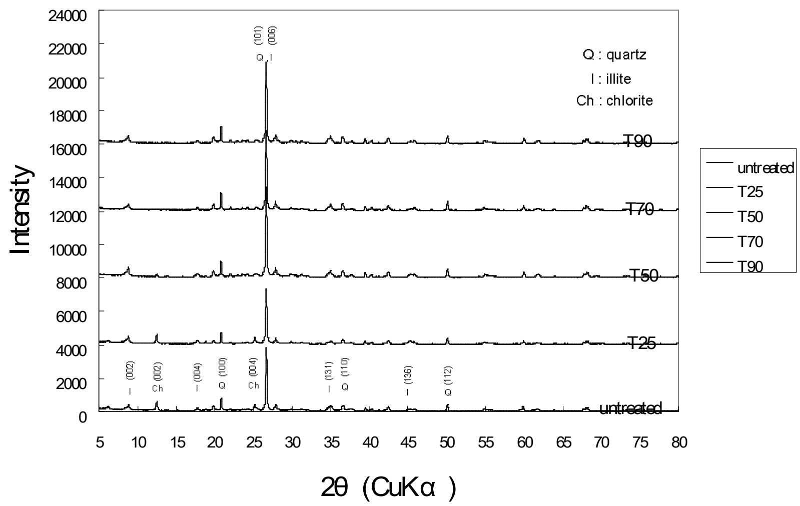

Figure 3. The spectrum of x-ray diffraction for 5N HCl sediment soil treatment.

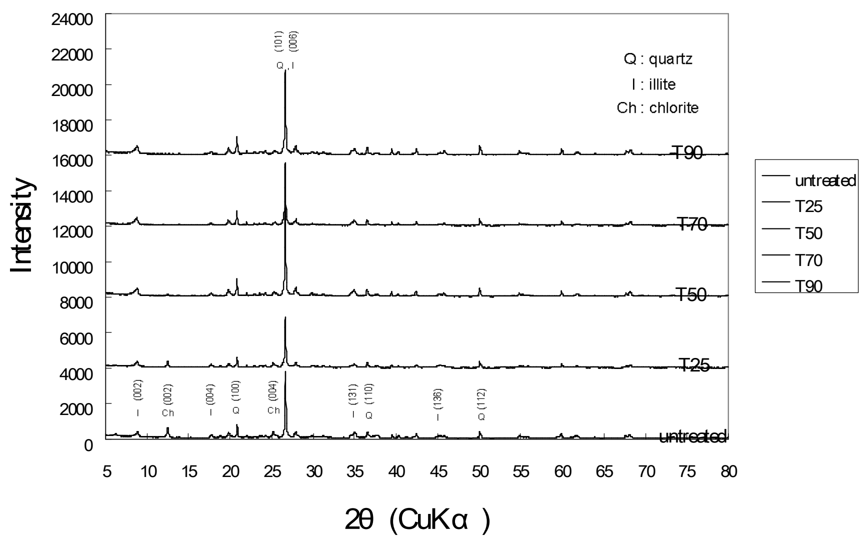

Figure 4. The spectrum of x-ray diffraction for 5N HNO_3 sediment soil treatment.

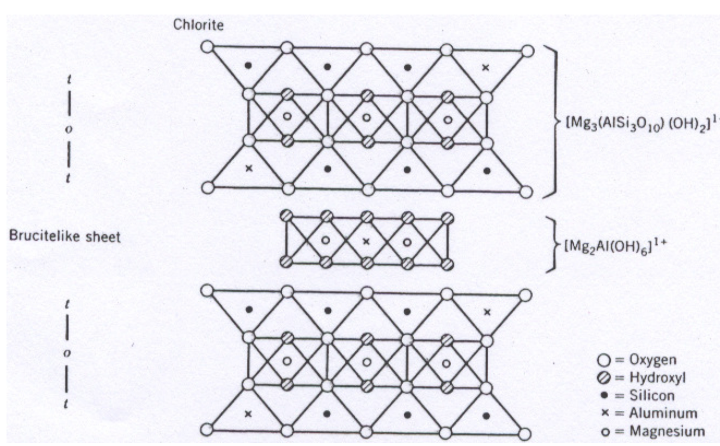

Figure 5. The chlorite ore in a layered silicate with a structure of 2:1:1.

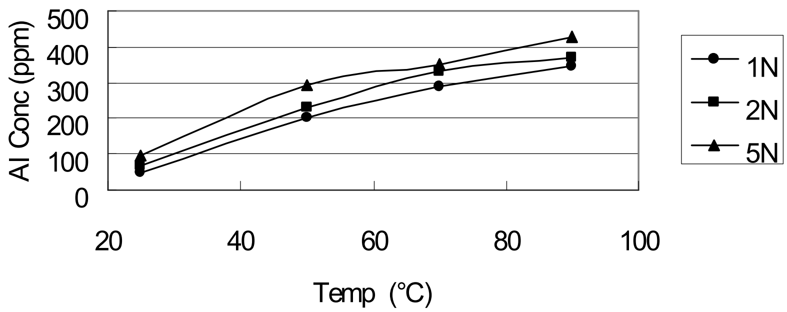

Figure 6. Sediment soil after 8 h H_2SO_4 treatment under three normality and four temperatures.

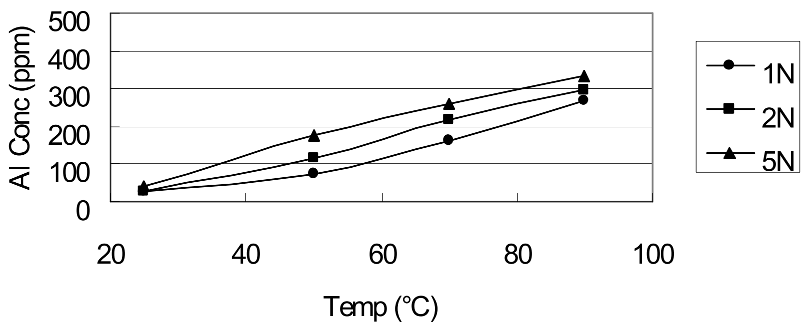

Figure 7. Sediment soil after 8 h HCl treatment under three normality and four temperatures.

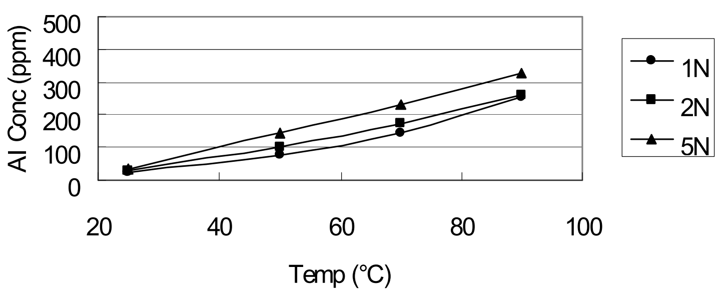

Figure 8. Sediment soil after 8 h HNO_3 treatment under three normality and four temperatures.

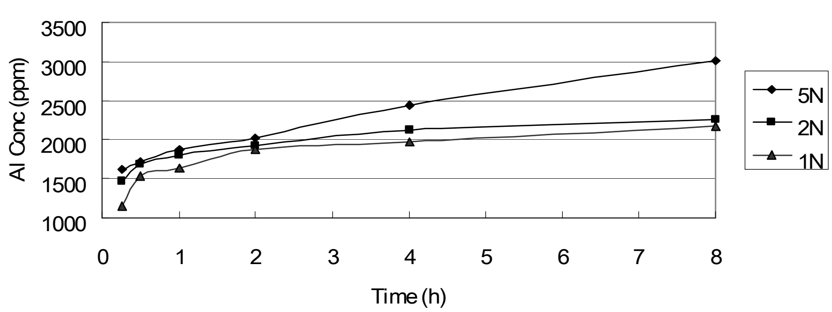

Figure 9. Sediment soil after 90°C H_2SO_4 treatment within 8 h in three normality.

Table 2. The maximum Aluminum removal from reservoir sediment soil by acids

solution	normality	temperature	time	the maximum extraction of Al^{3+}
sulfuric acid	5N	90 Celsius	8 hr	3019 ppm
hydrochloric acid	5N	90 Celsius	8 hr	2173 ppm
nitric acid	5N	90 Celsius	8 hr	2600 ppm

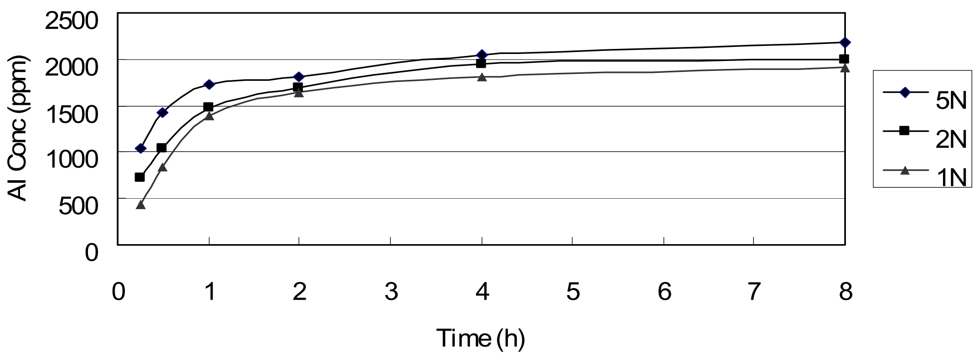

Figure 10. Sediment soil after 90 Celsius HCl treatment within 8 h in three normality.

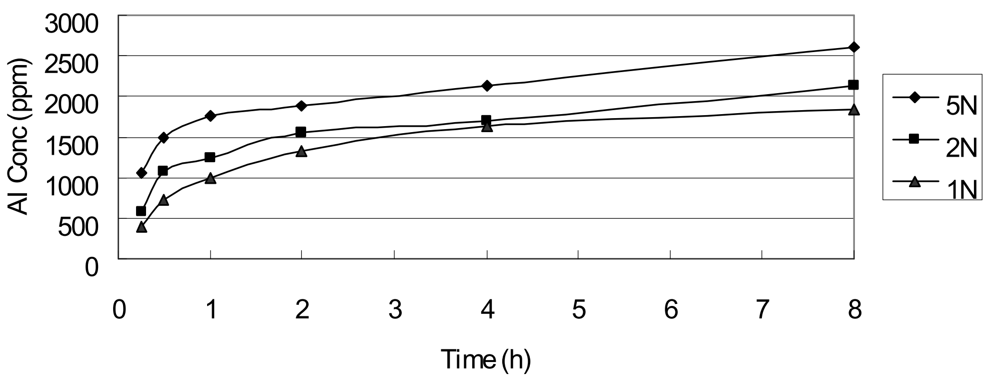

Figure 11. Sediment soil after 90 Celsius HNO_3 treatment within 8 h in three normality.

reservoir sediment, as shown in Table 2. We can therefore, determine sulfuric acid as the best aluminum leaching solution for the optimal operating conditions in this study.

Conclusions

The following conclusions were drawn from the present investigation: 1. By using acid solutions to extract aluminum ion from reservoir sediment, there is a distinct trend for normality, temperature and time. That is, the removal efficiency is positively correlated to the operating parameters; 2. Comparing the three acids, sulfuric acid achieves the best aluminum removal from sediment soil under the same normality, temperature and time. As for the optimal operating conditions, we set concentration at 5 N, the temperature at 90°C and a reaction time of 8 h. Nevertheless, the sulfuric acid is still the best solution to obtain the maximum extraction; 3. In this study, aluminum ion (Al^{3+}) is the target to be eliminated from reservoir sediment since it takes up most of the non-silicate composition, while significantly reducing the hydration capacity of sediment. There are still some topics for study for magnesium or iron within sediment which may also effect the hydration of soil; 4. Although, the effect of acids to extract heavy metals for preparation lightweight aggregate is significant, it also alters some soil chemical properties. If it is applied to *in situ* leaching for soil remediation, we should consider the concentration of reagents, chelating agents and auxiliaries (Fawzy, 2008). Otherwise, soil remediation for sustainable land usage may not be as good as expected.

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