Dissolution behavior of representative elements from red mud (RM) by leaching with titanium white waste acid (TWWA)

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Received: 18 January 2022 / Accepted: 21 May 2022 / Published online: 30 May 2022
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Abstract
Titanium white waste acid (TWWA) was used to dissolve the representative elements from red mud (RM) to achieve the goal of “treating waste with waste.” The leaching parameters on the leaching efficiency of Na, Sc, and Al were investigated, in which the analysis of XRD and SEM–EDS on RM and leaching residue was performed. The leaching kinetics of Na, Sc, and Al was studied with unreacted shrinking core model (USCM). The results show that the dealkalization efficiency was close to 100%, and the leaching efficiency of Sc and Al was 82% and 75%, respectively. Cancrinite was dissolved from RM, and then the elements such as Na, Al, and Ca reacted with H2SO4 of TWWA. Na existed in the leaching liquor in the form of ions. Ca reacted with sulfuric acid to form anhydrite, which existed in the leaching residue. The particles of RM became smaller and dispersed with each other by acid leaching. The leaching apparent activation energy of Na, Sc, and Al was 4.947 kJ/mol, 6.361 kJ/mol, and 31.666 kJ/mol, respectively. The leaching kinetic equation of Na, Sc, and Al was

\[ 1 - \alpha - (1 - \alpha)^{-2/3} - 1 = 67.12 \cdot \exp[-3808.8/T] \cdot t \]  

by joint action, respectively.

Keywords Dissolution behavior · Representative elements · Leaching · RM · TWWA

Introduction
Red mud (RM) is a strong alkaline solid waste discharged from alumina production of bauxite, which contains a large amount of iron oxide resulted in its red earthy form. About 1.0–1.8 tons of RM would be discharged for per ton of alumina production. China discharges 100 million tons of RM every year as a large country of alumina production (Jin et al. 2021; Xu et al. 2021). At present, the accumulated total amount of RM has exceeded 400 million tons. RM is also a kind of harmful pollution source because of its high sodium content. It is urgent to make full use of RM with the increasing storage of RM and the increasingly serious environmental pollution (Liu and Naidu 2014; Smiciklas et al. 2013). According to the physical and chemical properties of RM, the current research mainly focuses on the preparation of building materials, adsorption materials, and the recovery of valuable metals (Bao et al. 2021; Li et al. 2021a, b, c, d; Lyu et al. 2021; Wu et al. 2021; Zhang et al. 2020). RM also contains a lot of aluminum (Al), iron (Fe), and trace of scandium (Sc) and vanadium (V) as an important secondary resource. Therefore, the recovery of valuable metals from RM has been attracted more and more attention (Li et al. 2021a, b, c, d; Xu et al. 2020; Deng et al. 2017). The particle size of RM is very small and exceeds the minimum limit of gravity separation, flotation, and other physical methods. Furthermore, the mineral composition of RM is different from bauxite, in which Na, Al, Sc, and other elements mostly exist in the lattice of aluminosilicate. It also leads to the difficulty for separation and recovery of valuable components by the physical methods (Li et al. 2021a, b, c, d). Therefore, the technology of hydrometallurgy was mainly applied for the recovery of valuable metals, especially rare metals from RM. The acid leaching process (including sulfuric
acid, hydrochloric acid, oxalic acid, etc.) was usually operated for the dissolution of the metals, in which a lot of acid could be consumed. And then, the solvent extraction was carried out for the separation and purification of metals from the acid leaching solution (Wang et al. 2021a, b; Zhang et al. 2021a, b; Li et al. 2021a, b, c, d).

Titanium white waste acid (TWWA) is the hydrolytic waste liquid produced from the production of titanium dioxide by sulfuric acid method, which is highly acidic and rich in many kinds of metal ions. Approximately 5–6 tons of TWWA with concentration of 20% (v/v) would be produced for per ton of titanium dioxide production. The direct discharge of TWWA cannot only affect the water quality, acidify the soil, and break the ecological balance, but also restrict the development of agriculture and infringe the safety of drinking water (Li and Dai 2014; Song and Wang 2019; Feng et al. 2018). At present, the treatment of TWWA mainly included neutralization method and comprehensive method. Neutralization process was to add the alkaline substances into the wastewater, and then it was discharged at pH value of 6–8, in which the alkaline substances included lime, limestone, soda, caustic soda, etc. The comprehensive method was mainly based on the comprehensive treatment and resource utilization of TWWA (Hu et al. 2020a, b). For example, the extraction technology was operated for the recovery of Sc, V, and other rare metals. The crystallization technology was used for the recovery of Fe, Al, and Ti (Zhou et al. 2020a, b; Song et al. 2021; Feng et al. 2016). However, the strong acidity of TWWA limited the comprehensive utilization of solvent extraction and crystallization, in which a large amount of alkali was needed to adjust the pH value of the solution to meet the operation requirement. Therefore, the scholar has put forward a research idea on the recovery of V from vanadium-bearing steel slag with acid leaching by using TWWA (Zhang et al. 2021a, b).

Significantly, TWWA was different from the pure solution of sulfuric acid, which also contained a large number of Fe and Al, as well as a certain amount of rare metal such as Ti, V, and Sc. It was still worth studying and analyzing that the existence of these metal ions could affect the dissolution of components from RM. Therefore, an idea of “treating waste with waste” was put forward in this paper, where the leaching process of RM with TWWA was carried out. The dissolution behavior and leaching kinetics characteristics of representative elements from RM were investigated. The structural Na was the main alkaline pollution source in the RM, in which Al belonged a non-ferrous metal with high content, and Sc was a rare metal with strategic value. Therefore, the three elements of Na, Al, and Sc were selected as the representative elements. The investigation may provide a new idea and method for effective comprehensive utilization of RM and TWWA.

**Experimental**

**Materials**

The RM sample was collected from Henan province, China. The particle size of RM was less than 30 μm accounted for 100%. The main composition and functional group of RM was analyzed by using inductively coupled plasma-atomic emission spectrometry (ICP-AES) (Hossain et al. 2021; Feng 2021) and Fourier transform infrared (FT-IR), respectively. The results are shown in Table 1 and Fig. 1.

The RM mainly included the oxides of Si, Fe, Al, Ti, Ca, and Na from Table 1. Na was the main alkaline component of the RM sample. Al and Fe were the main valuable metals, in which the content of Al (26.28%) was obviously more than that of Fe (16.05%). Sc existed in the RM with the grade of 0.02% as an important rare earth element. It was necessary to study the leaching behavior of Na, Al, and Sc from the RM.

It can be seen from Fig. 1 that there were some obvious absorption peaks at 3445 cm\(^{-1}\), 1630 cm\(^{-1}\), 1420 cm\(^{-1}\), 1113 cm\(^{-1}\), 1004 cm\(^{-1}\), 866 cm\(^{-1}\), 680 cm\(^{-1}\), 620 cm\(^{-1}\), and 566 cm\(^{-1}\) in the FT-IR spectrum of RM sample. The broad absorption band at 3445 cm\(^{-1}\) in the spectrum was caused by the contraction vibration of O–H bond from water molecules in various states (mainly adsorbed water and crystal water).

### Table 1 Composition and content of RM (wt.%)

| Composition | Al\(_2\)O\(_3\) | SiO\(_2\) | Fe\(_2\)O\(_3\) | CaO | Na\(_2\)O | TiO\(_2\) | K\(_2\)O | MgO | Sc\(_2\)O\(_3\) |
|-------------|---------------|----------|----------------|-----|----------|----------|--------|-----|---------------|
| Content     | 28.05         | 26.28    | 16.05          | 15.68 | 5.26    | 4.39     | 1.21   | 0.87 | 0.02          |

![Infrared spectrum of RM](image)
and it may also be the stretching vibration of -OH bond in the gibbsite (Al(OH)₃). The absorption peak at 1630 cm⁻¹ was resulted from the vibration of Si–O-Si, and the absorption band at 1420 cm⁻¹ was caused by the stretching vibration of CO₃²⁻. The bending vibration of -OH in gibbsite resulted in the absorption band at 1004 cm⁻¹, and the absorption band at 620 cm⁻¹ and 566 cm⁻¹ was caused by the vibration of diaspore except for -OH.

The sample of TWWA was collected from Henan province, in which the main composition and concentration are shown in Table 2. The hydrogen ion concentration in H₂SO₄ of TWWA was determined by acid–base titration (Feng 2018). The concentrations of other metal ions were also determined by ICP-AES.

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The TWWA sample contained a large amount of H₂SO₄ (198.6 g/L), which may be used to leach RM by replacing the pure H₂SO₄. Furthermore, it also contained Al iron (3.3 g/L), Fe ion (23.9 g/L), and a certain amount of rare metal ions such as Ti, V, and Sc. Therefore, it was necessary to investigate the impact of TWWA on the dissolution of elements from RM in the leaching experiments.

**Methods**

The RM of 50 g with a certain volume of TWWA were placed into the beaker according to different liquid-to-solid ratios (e.g., 3 mL/g, 5 mL/g, 7 mL/g, 9 mL/g) and then heated on the magnetic stirrer. The leaching experiments were carried...
out under different conditions of stirring speed (e.g., 100 r/min, 200 r/min, 300 r/min, 400 r/min, 500 r/min), reaction temperature (e.g., 25 °C, 50 °C, 75 °C, 100 °C), and reaction time (e.g., 0.5 h, 1.0 h, 1.5 h, 2.0 h). The leaching solution and leaching residue were obtained by filtration. The leaching efficiency of metals can be expressed as follows:

$$a = \frac{(mq - np)}{mq} \times 100\%$$

where $a$ represents the leaching efficiency of metals (%), $m$ represents the weight of RM sample (g), $q$ represents the grade of metals in the RM (%), $n$ represents weight of leaching residue (g), and $p$ represents the grade of metals in the leaching residue (%).

**Analytical methods**

The components and content of RM and leaching residue were analyzed by using ICP-AES (ICAP6300, America). The XRD analysis (D8ADVANCE, Germany) of the RM and leaching residue was carried out. The SEM–EDS analysis (JSM-5600LV and IE 300 X, Japan) of RM and leaching residue was performed. The FT-IR (Spectrum100, America) was used for the functional group analysis of RM. The leaching kinetics was carried out with unreacted shrinking core model (USCM).

### Results and discussions

#### Leaching parameters

The effects of leaching temperature, liquid-to-solid ratio, stirring speed, and reaction time on the dissolution of Na, Sc, and Al from RM were investigated, and the results are shown in Fig. 2.

The dissolution efficiency of Sc, Al, and Na showed an increasing trend by increasing reaction temperature, in which the dissolution efficiency of Al increased significantly than that of Sc and Na (Fig. 2a). The dealkalization efficiency of RM presented by leaching efficiency of Na could reach 99% at 100 °C, where the recovery of Sc and Al was 82% and 73%, respectively. The leaching process between RM and TWWA belonged a chemical reaction of acid and base. Thus, the rate constant of chemical reaction and diffusion process could be greater with a higher temperature (Pasechnik et al. 2021). The liquid-to-solid ratio could directly affect the pulp viscosity and acid content of the solid–liquid system (Abhilash et al. 2021). Therefore, the higher was the liquid–solid ratio, the lower was the pulp viscosity. Furthermore, the higher acid content was obtained, in which the solubility of Na, Sc, and Al was more sufficient from RM with TWWA (Fig. 2b). It was difficult to stir evenly due to the high viscosity with the stirring speed of 100 r/min, where the removal efficiency of Na was less than 60%, and the leaching efficiencies of Sc and Al were less than 40% (see Fig. 2c). It reveals that the mixing of solid and liquid...
Fig. 4 SEM–EDS of (a) RM and (b) leaching residue
was more sufficient at higher stirring speed (i.e., 400 r/min), so the chemical reaction was accelerated with the increase of diffusion rate between the two phases (Zhu et al. 2015). From Fig. 2d, the dealkalization efficiency of RM increased from 72 to 99% with an increase of leaching time from 0.5 to 1.0 h, in which the leaching efficiency of Sc (from 71 to 82%) and Al (from 55 to 73%) was obtained, respectively. It indicates that the dissolution of components from the RM was more sufficient with a longer leaching time. The dealkalization efficiency of RM could reach more than 94% with the pure H₂SO₄ concentration of 1–1.6 mol/L according to the previous study (Hu et al. 2020a, b), which was consistent with the results of this study. The leaching of Al and Sc from RM required H₂SO₄ solution with more than 2 mol/L, in which the leaching efficiency could reach more than 80% (Lu et al. 2020). In addition, the leaching temperature of 90 °C and stirring speed of 450 r/min were necessary to obtain the high leaching efficiency of Al and Sc from RM by using pure H₂SO₄ solution (Sayan and Bayramoglu 2001), which was almost consistent with the leaching parameters of 100 °C and 300 r/min in this study. It is worth noting that the leaching agent was TWWA in this study, which could be used to replace the pure H₂SO₄ solution. The similar dissolution result of Na, Sc, and Al was obtained by controlling the parameters, which have saved H₂SO₄ consumption and reduced the economic cost.

Leaching mechanism analysis

The dissolution of Na, Sc, and Al was carried out from RM by using TWWA. In order to further explore the dissolution process of these elements, it was necessary to analyze the phase of RM and leaching residue. Under the conditions of 100 °C, 6 mL/g 400 r/min, and 1.0 h, the RM was leached with TWWA to obtain the leaching residue and leaching solution. The main composition and concentration of the leaching solution are shown in Table 3.

A large amount of H₂SO₄ was consumed by leaching RM with TWWA, in which the contents of Na, Al, Fe, and other elements in the leaching solution obviously increased compared to TWWA (see Table 2). It indicates that the TWWA could significantly dissolve the valuable components of RM. The decrease of acidity and the increase of metal ion concentration in the leaching solution were conducive to the further recovery of Sc and V with solvent extraction and the flocculant preparation of Al and Fe with polymerization (Zhou, et al. 2021; Zhu, et al. 2017, 2020).

The phase analysis and morphology analysis of RM and the leaching residue were performed by using X-ray diffraction (XRD) and scanning electron microscope-energy dispersive spectrometer (SEM–EDS), and the results are shown in Figs. 3 and 4, respectively.

It can be seen from Fig. 3a that the main mineral phases of RM included hematite, perovskite, gibbsite, cancrinite,
quartz, calcite, etc. Furthermore, there were also some minerals with no obvious characteristic peaks due to the less content and the overlapping spectral lines. In a word, the minerals were rich in the RM, but the occurrence state of metals was also very complex with coexisting minerals. Fe and Al mainly existed in the form of hematite (Fe$_2$O$_3$) and gibbsite (Al(OH)$_3$), respectively. However, Ti mainly existed in perovskite (CaTiO$_3$) and brookite (TiO$_2$). Cancrinite (Na$_6$Ca$_2$[AlSiO$_4$]$_8$[CO$_3$, SO$_4$](OH)$_2$) was a mineral with many elements including Na, Ca, Al, and Si. The rare earth element of Sc mainly existed in the minerals of hematite and gibbsite (Agrawal and Dhawan 2021). Figure 3b shows that the phase composition of leaching residue from RM has been obviously changed. The diffraction peaks of hematite, perovskite, gibbsite, and cancrinite in the leaching residue were weakened, which indicates that these minerals could be dissolved into the TWWA. The lattice of cancrinite was destroyed and resulted in the significant reaction of Na, Ca, and Al with H$_2$SO$_4$. The oxide of Na was easy to react with TWWA resulting in the existence of Na ions in the leaching solution. Most of Si dioxide remained in the leaching residue, so the diffraction peak of quartz increased significantly in the leaching residue. The new phase of anhydrite existed in the leaching residue, in which the oxide of Ca was easy to react with TWWA resulting in the generation of anhydrite and existed in the leaching residue. Furthermore, Ti in perovskite and Fe in hematite were also leached from RM with TWWA.

As shown in Fig. 4a, the surface morphology of RM could be directly observed with SEM. The result shows that the RM was mainly composed of multi-component granular or irregular block structure, which was disorderly distributed. The microstructure was relatively loose and the particles constituted a larger specific surface area. The small particles were the main parts, while the larger particles may be the calcite (CaCO$_3$), which constituted the framework of RM. Furthermore, it can be seen from the energy spectrum that the composition analysis results of RM are reliable with the result of ICP-AES (see Table 1). However, the Sc was not detected with EDS due to its low content in the RM. It can be seen from Fig. 4b that the particles became smaller and nearly spherical by leaching with TWWA, in which the particles were separated from each other. The energy spectrum analysis also shows that the content of Si in the leaching residue increased, and the Na was not detected, which indicates that the dealkalization process from RM was more complete. In addition, the content of Ca was not reduced compared with RM, which also verified the existence of anhydrite in

![Fig. 6 Fitting results of kinetic model on dealkalization. (a) external diffusion control, (b) chemical reaction control, (c) internal diffusion control, and (d) mixed control](image)
the leaching residue. Therefore, the leaching mechanism of RM by TWWA may be summarized as follows (see Fig. 5).

The minerals of cancrinite, hematite, perovskite, and gibbsite existed in the RM, in which the elements of Na, Sc, and Al was in the lattice of these minerals. The lattice of these minerals could be destroyed from RM by acid leaching with TWWA resulted in the dissolution of some elements (Na, Sc, Al, Fe, Ti, V, etc.) into the leaching solution. Quartz was one of the products from lattice destruction of cancrinite in the leaching residue, and anhydrite was produced by the reaction of CaO from cancrinite and $\text{H}_2\text{SO}_4$ from TWWA.

**Leaching kinetics**

In order to further explain the dissolution characteristics of Na, Sc, and Al from RM, it is necessary to investigate the leaching kinetics. The leaching process of RM with TWWA is essentially a heterogeneous reaction of liquid and solid. Combined with the analysis of SEM, the unreacted shrinking core model (USCM) can be used to describe and analyze the leaching process. The acid leaching process of RM mainly included the following five processes (Sun et al. 2021).

(A) The leaching agent moved from TWWA to the surface of RM particles (external diffusion).
(B) The leaching agent diffused to the reaction interface through the solid product layer (internal diffusion).
(C) Leaching agent reacted with unreacted RM at the reaction interface (chemical reaction).
(D) The reaction products diffused from the reaction interface to the boundary layer of solid particles (internal diffusion).
(E) The reaction products diffused from the surface of solid particles to the leaching solution (external diffusion).

The kinetics characteristic equations of the above different control steps are shown as follows:

\[
1 - (1 - a)^{2/3} = k_1 t \\
1 - (1 - a)^{1/3} = k_2 t \\
1 - 2a/3 - (1 - a)^{2/3} = k_3 t
\]

![Fig. 7 Simulation results of kinetic model on Sc leaching. (a) external diffusion control, (b) chemical reaction control, (c) internal diffusion control, and (d) mixed control](image-url)
where $a$ is the leaching efficiency of metals (%); $t$ is the reaction time (min); $k_1$, $k_2$, $k_3$, and $k_4$ is the rate constants of external diffusion control, chemical reaction control, internal diffusion control, and mixed control, respectively (min$^{-1}$).

\[
\ln(1-a)/3 + (1-a)^{-2/3} - 1 = k_4t
\]  

(5)

The leaching efficiency of Na, Sc, and Al from RM are, respectively, substituted into the kinetics control equations in Formulas (2)–(5) under different reaction temperatures. The results are shown in Figs. 6, 7, and 8, respectively.

It can be seen from Fig. 6 that the fitting degree with external diffusion and chemical reaction control was more

![Simulation results of kinetic model on Al leaching. (a) external diffusion control, (b) chemical reaction control, (c) internal diffusion control, and (d) mixed control.](image)

### Table 4 Kinetic model and parameters on leaching of Na, Sc, and Al from RM

| Species | Models                       | Parameters | Temperature (°C) |
|---------|------------------------------|------------|-----------------|
|         |                              | $k_1$      | 25   | 50   | 75   | 100  |
| Na      | $1 - (1-a)^{2/3}$            | $R^2$      | 0.0114 | 0.0135 | 0.0152 | 0.0171 |
|         |                              | $R^2$      | 0.9962 | 0.9990 | 0.9986 | 0.9975 |
| Sc      | $1 - 2a/3 - (1-a)^{2/3}$     | $k_2$      | 0.0016 | 0.0021 | 0.0024 | 0.0027 |
|         |                              | $R^2$      | 0.9990 | 0.9979 | 0.9954 | 0.9918 |
|         |                              | $R^2$      | 0.9990 | 0.9979 | 0.9954 | 0.9918 |
| Al      | $1 - 2a/3 - (1-a)^{2/3}$     | $k_3$      | 0.0003 | 0.0007 | 0.0012 | 0.0022 |
|         |                              | $R^2$      | 0.9960 | 0.9991 | 0.9953 | 0.9871 |
|         |                              | $R^2$      | 0.9916 | 0.9905 | 0.9988 | 0.9995 |
than 0.98 among the four kinetic models. It can be seen from Fig. 7 that the fitting degree of Sc leaching process with internal diffusion and joint control was more than 0.99. Figure 8 shows that the fitting degree of Al leaching process in RM with internal diffusion and joint control was more than 0.99. In order to further determine the kinetic equation of dissolution reaction of Na, Sc, and Al from RM, the kinetic data of the model with high fitting degree at corresponding temperature are listed in Table 4.

According to the kinetic data in Table 4, the leaching process of RM was further analyzed by Arrhenius equation (see Eq. 6) (Lin et al. 2021).

$$k = A \cdot \exp\left[-\frac{E_a}{(RT)}\right]$$

where $k$ is the rate constant, $A$ is the pre-exponential factor, and $E_a$ is the apparent activation energy of leaching reaction (kJ/mol), and $R$ is the molar gas constant (J·mol$^{-1}$·K$^{-1}$). The relationship between $\ln k$ and $1/T$ is constructed by taking the logarithm on both sides of Arrhenius equation (see Fig. 9).

According to the leaching kinetics theory, while the apparent activation energy ($E_a$) was less than 11 kJ/mol, the leaching process was mainly controlled by diffusion. While $E_a$ was more than 38 kJ/mol, the leaching process was mainly controlled by chemical reaction. The leaching process was jointly controlled by the two ways as $E_a$ was 11–38 kJ/mol (Zhou et al. 2020a, b). It can be seen from Fig. 9a that $E_a$ of dealkalization with the control of external diffusion was 4.947 kJ/mol, while it was 7.781 kJ/mol under the control of chemical reaction. Therefore, it is determined that the dealkalization process of RM was controlled by external diffusion, and its kinetic equation was $1 - (1 - a)^{2/3} = 0.084 \cdot \exp[-595.05/T] \cdot t$. Figure 9b shows that $E_a$ of Sc leaching was 10.479 kJ/mol under the combined control, while it was 6.361 kJ/mol under internal diffusion control. Therefore, it is determined that Sc leaching was controlled by internal diffusion, and the kinetic equation was $\ln(1 - a)/3 + (1 - a)^{-2/3} - 1 = 67.12 \cdot \exp[-3808.8/T] \cdot t$. In addition, $E_a$ could also explain the difficulty of leaching reaction. The result on $E_a$ of dealkalization process $< E_a$ of Sc leaching $< E_a$ of Al leaching was obtained according to
the analysis of leaching kinetics. It is indicated that the dealkalization process was easier to carry out than the leaching process of Sc and Al, which was consistent with the experimental results on the leaching of Na, Sc, and Al from RM with TWWA.

Conclusions

The dealkalization efficiency was close to 100%, and the leaching efficiency of Sc and Al was 82% and 75%, respectively, from RM with TWWA under the conditions of leaching temperature of 100 °C, liquid-to-solid ratio of 6 mL/g, stirring speed of 300 r/min, and reaction time of 1.0 h. The mineral composition of RM became smaller after the leaching process, and the leaching kinetics of Na, Sc, and Al can be analyzed with USCm. The dealkalization process of RM was controlled by external diffusion, and the kinetic equation was

\[
\ln(1 - a)^{2/3} = 0.084 \exp \left( -595.05 / T \right) \cdot t
\]

\[
E_a^{\text{of Na leaching}} = 6.361 \text{ kJ/mol, and the kinetic equation was:}
\]

\[
1 - (1 - a)^{2/3} = 0.021 \exp \left( -765.16 / T \right) \cdot t
\]

controlled by internal diffusion. \( E_a \) of Al leaching was 31.666 kJ/mol, and the kinetic equation was

\[
\ln(1 - a)/3 + (1 - a)^{2/3} - 1 = 67.12 \exp \left( -3808.8 / T \right) \cdot t
\]

controlled by diffusion and chemical reaction. Therefore, TWWA could be used as the leaching agent for the dissolution of representative elements from RM to achieve the aim of “treating waste with waste,” in which the different leaching characteristics of Na, Sc, and Al from RM were obtained with TWWA. This research could also provide the experimental basis and theoretical guidance for effective comprehensive utilization of RM and TWWA.

Author contribution Xiaobo Zhu, methodology, software, and writing; Chen Ma, data curation and writing—original draft preparation; Wang Li, investigation and writing—reviewing and editing.

Funding The research is financially supported by the National Natural Science Foundation of China (51904097 and 51804103), the Training Program for Young Backbone Teachers in Colleges and Universities of Henan Province (2019GGJS056), the Open Foundation of State Environmental Protection Key Laboratory of Mineral Metallurgical Resources Utilization and Pollution Control (HB202106), the Scientific and Technological Project of Henan Province (202102310548), and the Science Fund for Distinguished Young Scholars of Henan Polytechnic University (J2022-3).

Data availability Not applicable.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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