Research on Physical and Mechanical Indexes of Acidified Tailings Particles

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Abstract. Tailing acidification is a common objective phenomenon in sulfide mine tailings. In sulfide mines, the tailings sand particles are fine. With the accumulation of accumulation time, the sulfide minerals contained in the tailings will be oxidized to generate sulfate and sulfuric acid under the catalysis of oxidizing bacteria, water, oxygen and oxidant (such as Fe³⁺), and the acidic waste liquid will further undergo double decomposition reaction with metal oxides in the tailings to generate insoluble precipitates, which will weaken the shear strength of the tailings. It affects the stability of tailings. The author studies the stability of ore bodies after tailings acidification by laboratory experiments. It is found that tailings acidification will change the structural characteristics of soil and affect the shear strength of tailings soil itself.

1. Introduction

There are a lot of researches on the specific causes of tailings accidents in the literature at home and abroad[1-5]. Scholars pay attention to the influence of stratum lithology, gravity, rainfall and so on on the mechanical properties of tailings ponds, so as to evaluate their overall impact on tailings ponds, but few scholars have made research on the influence of tailings acidification. For metal sulfide mines, the impact of tailings acidification on the whole can not be ignored.

The chemical, physical and mechanical properties of tailings sand, such as mineral composition, gradation, density, permeability, compressibility and shear strength, will change with time, thus changing the chemical characteristics, seepage characteristics and stress characteristics of tailings dam. One of the important reasons for the instability and failure of tailings dam is tailings acidification, which will cause serious pollution to the surrounding environment in case of accidents [6].

In metal sulfide mines, there are two reasons for the acidic conditions of mineral oxidation. First, in the process of mineral washing, excessive acidic additives are added in order to extract the necessary components. These acidic additives will follow the tailings slurry formed after mineral washing and enter the tailings pond, so that the tailings sand of the tailings pond is in an acidic environment; Second, under the catalytic action of oxidizing bacteria, water, oxygen and oxidant (such as Fe³⁺), the sulfide minerals (pyrite) contained in the tailings are oxidized to generate sulfuric acid.

When the acid potential of sulfide tailings exceeds the acid neutralization ability provided by alkaline minerals contained in tailings, tailings acidification occurs, and AMD (acid mine drainage) is released through water infiltration. The author simulates the influence of this AMD on ore bodies.
through experiments, and studies the changes of grain size distribution, specific surface area and shear strength of ore bodies.

2. Experimental Materials and scheme

2.1. Experimental Materials

The material used in this test comes from a tailings pond in Shuikoushan, Hunan Province, which is a typical lead-zinc tailings. The acidification of tailings dam in the air mainly occurs in 0-20cm of tailings surface [7]. In order to reduce the influence of environment on the tailings sand samples taken, the surface tailings sand should be removed 20cm before sampling, and the cover sand should be removed from the lower layer. Sampling point is 50m away from sand discharge pipe.

X-ray fluorescence spectrometry (XRF) scanning experiment was used to measure the types and contents of elements contained in the sample, as shown in the following table:

| Element | O   | Si  | Ca  | Fe  | S   | Al  | K   | Mg  | P   |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Proportion | 47.016 | 25.682 | 9.933 | 8.012 | 5.092 | 2.316 | 0.664 | 0.132 | 0.118 |

Table 1. Element content analysis of undisturbed tailings sand/%

| Compound | SiO₂ | CaO  | SO₃ | Fe₂O₃ | Al₂O₃ | K₂O | TiO₂ | MgO  | P₂O₅ |
|----------|-----|-----|-----|-------|-------|-----|------|------|------|
| Proportion | 54.942 | 13.897 | 12.715 | 11.454 | 4.3764 | 0.799 | 0.302 | 0.218 | 0.269 |

Table 2. Analysis of main compounds content in undisturbed tailings sand/%

Bringing the formula MAP = total pyrite S(%)×30.6ANC, NAPP=MAP-ANC(ANC — H₂SO₄, kg·t⁻¹), it is calculated that NAPP is far greater than 0, which indicates that the tailings sand has high acid production potential. Therefore, the tailings sand sample meets the requirements of this test.

2.2. Test instrument and Scheme

The author studied the acidification of tailings by dynamic immersion experiment. Five 5L PVC barrels are selected, and the barrels are numbered A00, A25, A50, A75 and A100 (corresponding acidizing degrees are 0%, 25%, 50%, 75% and 100% respectively). The original 50kg tailings sand samples are dried in a dryer, and then 10kg is weighed. The dried tailings sand is divided into five groups, each group is 2kg. According to the different oxidation degree, the prepared hydrogen peroxide solution is added to barrels A00, A25, A50, A75 and A100 respectively.

As the early reaction between pyrite and hydrogen peroxide is too intense (a large amount of pungent gas is produced), five groups of samples are transferred to a 20L reaction barrel for reaction, and then transferred to a 5L PVC barrel for long-term soaking after the reaction is completed. In order to make the reaction more fully proceed, the reactants are stirred with wooden sticks during the reaction, once every 24 hours, for 7 times, and soaked for 168 hours.

In order to understand the structure and physical and mechanical properties of tailings sand before and after pyrite oxidation, the author carried out particle analysis, ICP iron analysis, specific surface area measurement and direct shear test.

3. Experimental reaction mechanism

Acidification of pyrite is a very long process under natural conditions. Canada has conducted a survey on the generation and duration of acid water from tailings, and found that some tailings ponds still produce a large amount of acid wastewater after being closed for hundreds of years [8]. In Peggy Lee Kam-Man, the characteristics of pyrite acidification were explored by dynamic leaching test, and weathering simulation test was carried out for 50 weeks. After 16 weeks, the pH value decreased obviously [9].

The conventional experimental operation method can not simulate the acidification process of tailings in a limited time, and adding catalysts can greatly shorten the reaction time. If you want to
simulate the oxidation-acidification of tailings under natural conditions in laboratory conditions, you must add corresponding catalysts to speed up the reaction process and shorten the reaction cycle.

By comparing the effects of potassium permanganate, calcium hypochlorite, ferric sulfate and hydrogen peroxide on the oxidation of arsenopyrite, it is found that hydrogen peroxide has the best effect [10]. Under laboratory conditions, hydrogen peroxide can react with FeS2 to generate Fe^3+ and SO_4^{2-}, which is consistent with the reaction mechanism and products of FeS2 under natural oxidation conditions. The reaction equation is as follow:

\[ 2\text{FeS}_2 + 15\text{H}_2\text{O} = \text{Fe}_2(\text{SO}_4)_3 + \text{H}_2\text{SO}_4 + \text{H}_2\text{O} \] (1)

Under laboratory conditions, sulfuric acid produced by catalytic oxidation of pyrite by hydrogen peroxide can continue to undergo double decomposition reaction with CaO in tailings sand, and CaSO_4 produced by the reaction is slightly soluble in water and adheres to the surface of calcium carbonate to prevent the reaction from proceeding, so the acidification reaction of CaO cannot proceed to the end.

To sum up, the dissolution of tailings sand solid particles caused by chemical reaction is mainly due to the dissolution of FeS2-containing solid particles, and the dissolution of CaO-containing solid particles only accounts for a small part of the total dissolution.

4 Experimental results and Analysis

4.1. Change of particle size

The different acidification degree of tailings will lead to the change of the microstructure of tailings, and the particle size of tailings is closely related to the mechanical properties of tailings.

Table 3. Results of particle size and mass ratio of tailings sand under diverse oxidation degrees

| Num | Sand/mm | Silt/mm |
|-----|---------|---------|
|     | >2      | 1-2     | 0.5-1   | 0.25-0.5 | 0.075-0.25 | <0.075 |
| A00 | 0.03%   | 0.09%   | 7.27%   | 25.11%   | 41.76%     | 25.73%  |
| A25 | 0.02%   | 0.09%   | 7.26%   | 24.29%   | 44.02%     | 24.34%  |
| A50 | 0.02%   | 0.08%   | 7.25%   | 24.27%   | 45.21%     | 23.16%  |
| A75 | 0.02%   | 0.08%   | 7.05%   | 23.71%   | 48.00%     | 21.14%  |
| A100| 0.02%   | 0.09%   | 6.87%   | 23.39%   | 48.92%     | 20.71%  |

Combined with formula (1), with the deepening of oxidation and acidification, coarse-grained tailings sand containing CaO and FeS2 changed into fine-grained sand after oxidative decomposition and dissolution of alkaline substances, which gradually reduced the tailings sand with particle diameter > 0.25mm in the test group.

Coarse-grained tailings sand containing CaO and FeS2 is changed into fine-grained sand after oxidative decomposition and dissolution of alkaline substances, so that the number of sand with particle size in the range of 0.075-0.25mm gradually increases.

The Fe_2(SO_4)_3 generated after FeS2 acidification is dissolved in water, and the tailings sand powder with particle size less than 0.075mm has large specific surface area, large contact surface with solution, high reactivity and high solubility, so some tailings sand powder containing FeS2 is dissolved in acidic liquid, which leads to the mass reduction of the powder with particle size less than 0.075mm with the deepening of oxidation and acidification.

4.2. Change of specific surface area

Specific surface area refers to the total area per unit mass of materials, and its unit is m^2/g. According to different research purposes, specific surface area consists of three types: inner specific surface area, outer specific surface area and total specific surface area [12]. The specific surface area measurement
test was used to judge the change of specific surface area of tailings sand per unit mass, which reflected the acidification of tailings sand per unit mass from the side.

Table 4. Specific surface area of ore under different acidification degrees (m²/g)

| Acidification degree | A00 | A25 | A50 | A75 | A100 |
|----------------------|-----|-----|-----|-----|------|
| Single point surface area | 2.886 | 2.921 | 3.179 | 3.368 | 3.585 |
| BET Specific surface area | 3.011 | 3.175 | 3.357 | 3.784 | 3.928 |
| Langmuir surface area | 15.379 | 17.227 | 17.652 | 18.343 | 18.734 |

The single point surface area, BET specific surface area and Langmuir surface area of the tailings sand test samples all increase with the deepening of acidification degree. With the increase of specific surface area, the total area of tailings sand per unit mass becomes larger, the contact surface with solution increases, and the reaction activity increases, resulting in smaller particle diameter. The reason is that with the deepening of acidification, more coarse tailings sand particles containing CaO and FeS₂ undergo acidification and decomposition, resulting in smaller sand particles and particles.

4.3. Changes in shear strength

The shear strength of soil was measured by Direct shear test. The shear strength indexes, cohesion C and internal friction angle φ, obtained from the direct shear test have certain significance for studying the change of shear strength of tailings sand under different acidification conditions.

Table 5. Numerical value of shear strength under different acidizing degrees

| Num | A00 | A25 | A50 | A75 | A100 |
|-----|-----|-----|-----|-----|------|
| C   | 4.2 | 2.63 | 8.6 | 5.6 | 5.16 |
| Φ   | 31.8 | 31.3 | 31.2 | 30.5 | 29.5 |

The test adopts fast shear method, and the cohesive force C is caused by mutual attraction or repulsion between tailings sand particles. The cohesive force depends on various forces between soil particles, including electrostatic force, cementation and so on.

The internal friction angle φ represents the internal friction force of soil, which reflects the friction characteristics of soil, including overcoming the surface friction force caused by the rough surface of soil particles when they slide each other, and the occlusal friction caused by the movement of embedded, interlocked and disengaged soil particles [13]. Generally speaking, the greater the internal friction angle of tailings sand, the higher the strength of sand body.

It can be seen from Table 5 that with the deepening of oxidation and acidification, the internal friction angle φ of tailings decreases gradually; cohesion C is distributed discretely and changes discretely within a certain range.

The research shows that the coarse sand plays the role of skeleton and the fine sand plays the role of filling. At this time, the strength characteristics of the mixed sand are basically stable. When the coarse particles gradually decrease and the fine particles increase due to external influence, the fine particles will separate more and more coarse particles and make these coarse particles free in the fine particles [14].

In the particle analysis test, it has been found that with the deepening of acidification, the mass proportion of sand with particle size greater than 0.25mm gradually decreases, while that of sand with particle size less than 0.25mm gradually increases. The original coarse particles of tailings sand undergo different degrees of oxidative hydrolysis, and the particle size becomes smaller, which makes more and more coarse particles surrounded by fine particles, resulting in weakening of surface friction and occlusal friction between particles and weakening of internal friction of tailings sand.

5. Conclusion

(1) Hydrogen peroxide is used as catalyst to accelerate the oxidation process of tailings sand, so as to simulate the natural oxidation process of tailings sand under laboratory conditions (hydrogen peroxide
mainly reacts with pyrite in tailings sand to generate Fe$_2$(SO$_4$)$_3$ and H$_2$SO$_4$, which is consistent with the products generated by pyrite in natural state). H$_2$SO$_4$ generated by oxidation will continue to react with other metal oxides in the tailings, mainly because CaSO$_4$ which is slightly soluble in water is generated by CaO and H$_2$SO$_4$, and heavy metal ions such as Zn, As, Al and Mg in the tailings are dissolved and released in acidic solution.

(2) With the deepening of pyrite oxidation-acidification degree, the proportion of sand with particle size larger than 0.25mm decreases gradually, while that of sand with particle size smaller than 0.25mm increases gradually. There are two kinds of sand with particle size less than 0.25mm: sand with particle size in the range of 0.075-0.25mm has a gradually increasing mass proportion, while sand with particle size less than 0.075mm has a gradually decreasing mass proportion, but the mass percentage of sand with particle size less than 0.25mm has an overall trend of increasing;

(3) With the deepening of oxidation and acidification, the internal friction angle $\phi$ of tailings decreases gradually; cohesion $c$ is distributed discretely and fluctuates irregularly within a certain range.

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