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Research on the mechanism for chemical clogging and its effect on the stability of tailing dam

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The stability of tailing dam has an important influence on the surrounding ecological environment and the security and property of people. This article, from the micro perspective, analyzes of the water-tailing chemical interactions and process and analyzes its effects on tailing micro structure and dam stability. The experimental results show that ferrous iron in water(PH=9.5-10.3) is constantly in contact with the air and then produces a series of reactions such as oxidation, eventually becomes a clogging substance what mainly include $Fe(OH)_3$; the chemical clogging substances mainly include $Fe(OH)_3$, some cements and strong adsorption humus groups that will block the pore channels and absorb the ions or tailings in water to form a larger group that accumulating in porous media and drain mouths will result in poor seepage and affect its permeability; The chemical clogging can reduce the stability of tailing dam. Those researches of chemical process of tailing dam will provide directions references for tailing dam security-research and the improvement of tailing dam water-environment.

Keywords*:* Tailings dam, chemical clogging, tailing micro structure, stability

INTRODUCTION

Accidents with tailing dam breaching have occurred from time to time in recent years that not only cause enormous economic losses and casualties, but also cause serious environmental pollution and ecological destruction. Studying the mechanism of tailing dam breaching and analyzing the factors influencing dam stability will be of great importance to ensure that the tailing dam will be exploited safely and stably avoiding or reducing the occurrence of probable disasters thereby reducing the inevitable economic losses. A tailing dam is a structure not only storing tailings but also storing tailing water so that water is an important and influential factor as regards dam breach accidents and also an important factor that renders the geotechnical engineering problems more complex. Chemical reactions within the tailing dam, such as the precipitation and crystallization, produce a range of chemical substances that can jam the tailing dam pore channels, for instance sludge plugging, this will influence the dam drainage performance and reduce the safety of the tailing dam. The researches of water-soil interaction, Qiao Juan and Luo Xianqi [1] discussed the water effects on dam breach and made the following conclusion: the water effects on a dam mainly include the increasing downslide slope strength and reducing slope shear strength; Liu Jifeng [2] researched the change in the laws of slope soil cohesion and the internal friction angle for different water contents and the experiment showed that the internal friction angle (φ) appears to show a downward trend in the form of an exponential function with a water content upward trend and the cohesion appears as a trend first to increase and then to decrease in the form of a Gaussian function with the water content upward; Qin Huali [3] expounded the two ways the water acts on the dam slope and discussed the water effect on the stability of the dam body and its action mechanism; Xing ye [4] and Ma chixiang [5] studied the effect of combining the water-soil coupling interaction with an analysis of tailing dam stability and studying the water-soil coupling interaction of the tailing dam; Zandarina [6], Wang Feiyue [7], Yan Qiong [8] and Hu Jingyou [9] studied the seepage and stress fields of mine granular material and built an equation and calculation model considering tailing dam fluid-solid coupling at different conditions; Zhen Xunzhen [10] built a dam deformation model considering the chemistry, seepage and stress fields coupling and studied in depth the nonlinear compressibility-permeability mathematical model of dam deformation; Feng Xiating [11] built the convection-diffusion-reaction model considering the water-rock system based on the chemical kinetics theory, the solute transport theory and

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applied porosity to quantitatively describe the rock microstructure changes caused by the water-rock interaction; Zhang Xingui [12], from the chemical perspective, analyzed the chemical reactions following the water-soil interaction and analyzed the changes in the soil microstructure; Van Gulck [13] studied the mechanism of chemical and biological clogging in the dam porous media through researching the testing column; Rowe and Mclsaac [14] researched the debris-sand clogging phenomenon with solution permeating testing columns.

At present, many researches on stability of tailing dam mainly focus on the dam seepage and the water-soil physical interaction, but researches on water-soil chemical interaction are relatively fewer, So this article analyze the chemical reactions process at the condition of tailing dam specific water-environment, further discussing the clogging mechanism, the main clogging materials and the interactions between sludge plugging and seepage. Researches of chemical process in a dam not only provide directions for tailing dam security-research, but also provide references for improving the tailing dam water-environment and analyzing the chemical action effects on the tailing microscopic structure and the tailing dam stability. Researches of chemical process in a dam not only provide directions for tailing dam security-research, but also provide references for improving the tailing dam water-environment.

RESEARCH AND ANALYSIS ON CHEMICAL CLOGGING MECHANISM

Studying the tailing dam clogging problems, the key is to reveal the conditions, material sources and chemical reaction process of chemical clogging. With the aid of this research, we first collect relevant chemical data about tailing dam and other dam buildings, then forecast the contingent chemical clogging problems, thus providing a theoretical basis for the prevention and control of the engineering problems. Table 1 and table 2 list the main chemical composites of copper-lead-zinc ore tailings and tailing water (PH=9.5-10.3) .

Table 1. Main chemical composites of original tailing (% -mass percentage).

Sample 1 (original tailing)										
Element	Mg	Al	Si	S	K	Ca	Mn	Fe	Cu	Zn
Content	0.20	9.40	30.4	1.43	3.34	0.27	0.24	3.61	0.01	0.19
Sample 2 (original tailing)										
Element	Mg	Al	Si	S	K	Ca	Mn	Fe	Cu	Zn
Content	0.31	7.30	29.3	1.27	4.12	0.18	0.30	4.17	0.03	0.16

Table 2. Main chemical composites of tailing water (mg/L).

Sample 1 (tailing water)										
Ion	Fe^{3+}	Mg^{2+}	SO_4^{2-}	CO_3^{2-}	Cl^-	Ca^{2+}	Na^+	Al^{3+}	K^+	Zn^{2+}
Content	0.07	0.15	0.78	7.16	0.01	275	33.7	0.35	57.5	0.04
Sample 2 (tailing water)										
Ion	Fe^{3+}	Mg^{2+}	SO_4^{2-}	CO_3^{2-}	Cl^-	Ca^{2+}	Na^+	Al^{3+}	K^+	Zn^{2+}
Content	0.10	0.23	0.54	6.14	0.01	210	25.6	0.27	49.6	0.08

Table 3. Main composites of clogging matter (% -mass percentage).

Sample 1 (tailing before clogging)										
Element	Mg	Al	Si	S	K	Ca	Mn	Fe	Cu	Zn
Content	0.25	15.3	27.6	1.32	3.32	10.13	0.34	4.76	0.01	0.11
Sample 2 (tailing before clogging)										
Element	Mg	Al	Si	S	K	Ca	Mn	Fe	Cu	Zn
Content	0.31	2.70	25.2	0.96	3.56	12.85	0.27	5.35	0.04	0.13

From table 1 above, the main chemical composites of copper-lead-zinc ore tailings are Fe, Al, Si, Mg, K, S, but the Cu and Zn are less; Table 2 shows that the main chemical composites of tailing water are Ca^{2+}, K^+, Na^+, CO_3^{2-} with a relatively smaller content of Mg^{2+}, SO_4^{2-}, Cl^-. Analyzing the clogging substances, the main composites are listed in table 3.

From table 3, it is apparent that the matter containing Fe is more and accounts for almost all of the entire matter clogging. Meanwhile we must combine with the analysis of the XRD spectra of the clogging matters. In XRD, in order to confirm the existence of a material, we need to view whether the analysis line and the peak center of XRD line is closer, if closer, we will think the material existing. Combine with figure 1, the analysis line of $Fe(OH)_3$ is much closer with the peak center of XRD line, so we can determine that the main clogging material is $Fe(OH)_3$.

Both of Figure 2 and Figure 3 are the pictures of tailing SEM scans and reflect the characteristics of tailing surface. Figure 2 reflects the attached particles on tailing surface, such as sand, silt, clay. Figure 3 reflects the changes of tailing surface characteristics before and after chemical clogging. Before chemical clogging, the tailing surface is smooth and its attachments are less, but after chemical clogging, the tailing surface presents clustered structure and becomes more rough.

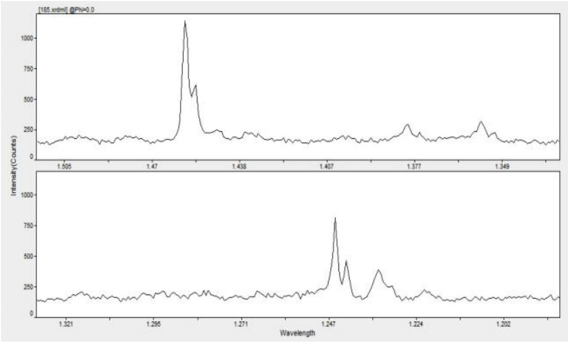


Fig. 1. XRD spectra of clogging matter.

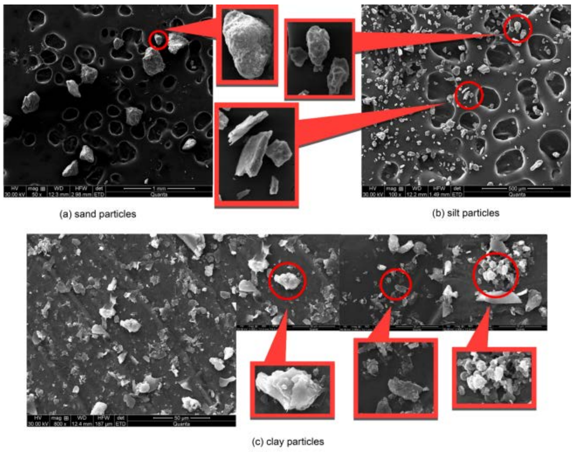
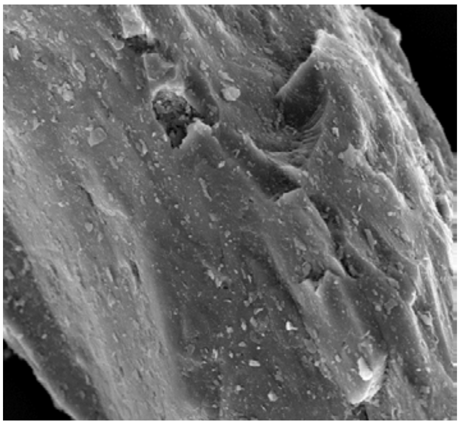
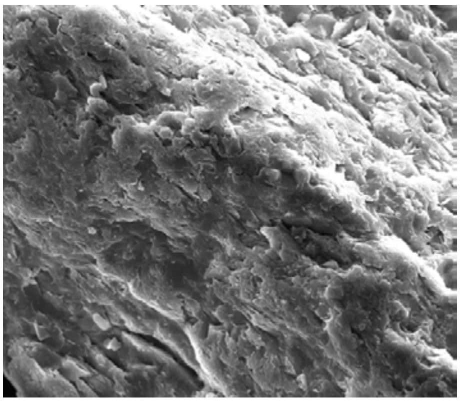


Fig. 2. Tailings SEM scans



a)



b)

Fig. 3. The microscopic surface of tailing: a) Common tailings; b) Tailings of chemical clogging.

By detecting copper-lead-zinc ore in tailing dam, it was found that the dam is in a good reducing condition so that iron exists mainly in a ferrous form. In accordance with the above analysis of the clogging materials, we know the main component of the clogging material is $Fe(OH)_3$. Therefore, the mechanism of chemical clogging within the tailing dam is: ferrous iron in water(PH=9.5-10.3) is constantly in contact with the air and preduces a series of reactions such as oxidation, eventually becomes a blocking substance with $Fe(OH)_3$ as the main clogging matter. The clogging substances accumulate in porous media and drain mouths that will result in poor seepage and affect its permeability.

According to the above analysis of copper-lead-zinc ore chemical clogging substance and the wholesome clogging process, the main chemical processes occur in the molybdenum mine tailing dam:

$4Fe^{2+}+O_2+2H_2O=4Fe^{3+}+4OH^-$;

$Fe^{3+}+3H_2O=Fe(OH)_3\downarrow+3H^+$;

$Fe^{2+}+2OH^-=Fe(OH)_2\downarrow$

$Fe(OH)_2+O_2+H_2O=Fe(OH)_3\downarrow$

$4Fe(HCO_3)_2+O_2+2H_2O=4Fe(OH)_3\downarrow+CO_2$;

$2FeS_2+4H_2O+7.5O_2=Fe_2O_3(s)+4SO_4^{2-}+8H^+$.

Over time, $Fe(OH)_3$ is also changed:

$2Fe(OH)_3\rightarrow Fe_2O_3+3H_2O$;

In addition to Fe, the tailing water also contains Ca, Cu, Mg and other elements that are in a free state in the dam, when contacting the oxidizing environment, these will generate insoluble materials; condensation cements manufactured by OH^- ions and certain metal cations not only embodying the tailing particles, but also adsorbing other ions in solution that is an important reason for chemical clogging.

$Ca^{2+}+2HCO_3^-\rightarrow CaCO_3\downarrow+CO_2+H_2O$;

$2Cu^{2+}+O_2+4e^-\rightarrow 2CuO(s)$;

$2Mg+O_2+4e^-\rightarrow 2MgO(s)$.

In addition the above main chemical reactions, since the tailing dam site are found near mountains, and the tailing water has chemical properties, so some animals and plants die under a cover of tailings, over time, these decomposed and form humus. Humus has a strong chelating effect and can combine organic substances in water by means of Van der waals force, the electrostatic interaction and hydrogen bonding interaction between metal ions and the ion bridge bond, when the water-environment is close to PH=9-10, the plant auxin can combine with humus by the bridge bond roles of some transition metal ions or some common metal ions (Ca^{2+}). The humus in the tailing dam can also combine with clay minerals by Fe^{3+} and Ca^{2+}.

Fulvic acid, the main component of humus, can combine with metal ions and organic matter in a dam by physical and chemical action and form groups with stronger adsorption ability. The whole process of dam chemical clogging can be expressed in the following figure 4:

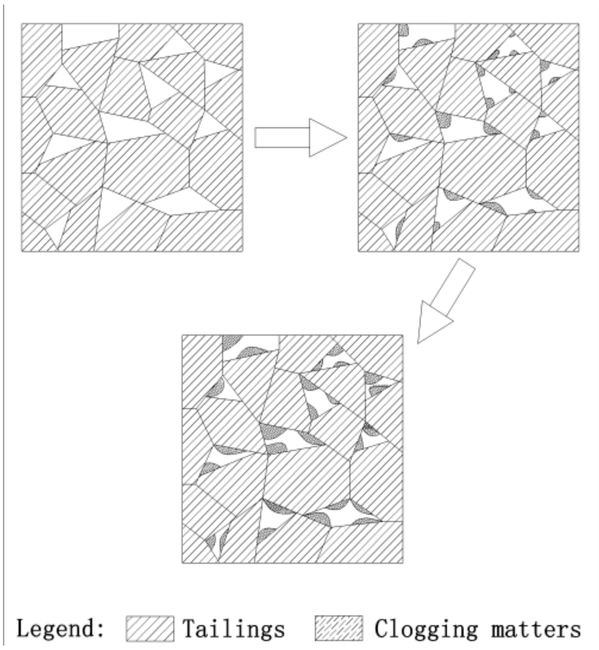


Fig. 4. Porosity changes over time.

From Figure 4 above, with tailings increasing, the chemical matter in the dam is replenished constantly so the chemical reactions taking place will be an ongoing process. The ongoing chemical reactions produce more chemical clogging matter, from the micro structure and the dam pore channels get narrower. Based on the above analysis, the chemical clogging substances mainly include $Fe(OH)_3$, some cements and strong adsorption humus groups that will jam the pore channels and absorb the ions or tailings in water to form a larger group. Tiny particles are the main product as a result of the physical clogging, since the chemical clogging makes the pore channels narrower, the original tiny particles can no longer cross the same channels and the long-term accumulation of fine materials will reduce the dam permeability.

ANALYSIS OF DAM STABILITY

Chemical clogging substances block pore channels by attachment and settlement so that increases the solution flow resistance in porous media and reduces the material migration ability in dam porous media, in addition, it can also change the micro structure of the tailings.

Influence of chemical clogging on the permeability coefficient

According to Darcy the empirical formula [15]:

$$Q = kiAt = k\frac{H}{L}At \tag{1}$$

$$k = \frac{QL}{HAt} \tag{2}$$

L -water permeation through the thickness of the soil; Q -seepage flow; t -seepage time; H -the upper and lower water surface height difference; A- the cross sectional area; k -the permeability coefficient.

Chemical clogging causes the resistance of the tailings water flow in the porous medium to increase resulting in a reduction of the seepage flow Q per unit time, with the seepage time increasing, according to the formula (2), the permeability coefficient k shows a trend to decline in the case of chemical clogging.

Influence of chemical clogging on volume-weight

Because the chemical clogging jams the inner pore channels of the tailing dam, it results in a decrease of the material migration ability in the pore channel and leads to the pore channel within tail ore per unit volume being blocked by the materials that do not migrate in time, causing an increase in the tail ore density per unit volume. In accordance with the above formula, we can come to the conclusion that the tail ore density gamma increases in the case of chemical clogging.

The expression for the formula of the gravity density is:

$$\gamma = \rho g \tag{3}$$

ρ -Soil density; g -Soil gravity acceleration

Influence of chemical clogging on the cohesion and internal friction angle

According to the soil test[16], the soil shear strength is expressed as a function of the normal total stress on the shear failure surface in Coulombs and the following general expression is put forward as suitable to evaluate cohesive soil:

$$\tau_f = c + \sigma \tan\varphi \tag{4}$$

τ_f -shear strength; σ -total stress; c -soil cohesion; φ -soil internal friction angle.

By means of Coulomb's law, the indexes which characterize the shear strength of tailing include the tailing internal friction angle and cohesion: the rougher the particle surface is, the higher the density is, so the larger the soil internal friction coefficient $\tan\varphi$ is; the cohesion between tailing particles depends on the connectivity between the particles and is related to the forces between these and the chemical reactions generated. As can be observed from figure 3, the surface roughness of the tailings increases after the chemical clogging, moreover, the chemical clogging reduces the material migration ability of the porous media, so it also makes the density of the tailings per unit volume increase. Finally, this may cause an increase in the internal friction coefficient $\tan\varphi$ and the combination of both affects the tail ore shear strength.

Influence of chemical clogging on stability of tailing dam

At the scene retrieved tailing samples include mainly the common tailings and the tailings at the clogging location. The saturated infiltration coefficient is measured by taking a constant head permeation test. The cohesion and internal friction angle are measured by a shear strength test. In addition, it also includes other tests, such as: density, volume-weight. The relevant key parameters for the molybdenum starter dam are chosen from similar earth-rock dam survey data[17] and the parameters of the shear strength of the saturated tailings chosen from the literature[18]. Other relative parameters get from indoor soil tests. All the needed parameters are shown in the following table 4.

Table 4. Physical and mechanical parameters of the tailings.

Material	γ(kN/m^3)	c(kPa)	φ($^\circ$)
Initial tailing dam	24.6	28.18	36.3
Medium tailing	26.4	13.9	31.3
Clogging matter	26.9	15.1	25.2
Fine tailing	26.7	0.64	19.5
Silty tailing	27.6	0.32	14.3

γ -Unit weight; c -Cohesion; φ -Internal friction angle.

Table 5. Stability coefficient of the tailing dam

State	Ordinary	Bishop	Janbu
Bc	1.181	1.357	1.216
Ac	1.047	1.057	1.047

Note: Bc -before clogging; Ac -after clogging

The stability of a tailing dam before and after chemical clogging is analyzed by slide5.0 and the whole tailing dam model is divided into four different materials: starter dam, medium tailing, fine tailing, silty tailing (from left to right) as illustrated in figure 5.

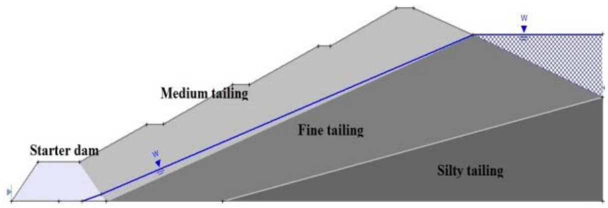


Fig. 5. Calculation section of tailing dam stability.

Clogging occurs mainly in the model corresponding to the position of medium tailing. When analyzing the stability of a tailing dam in the case of chemical clogging, the parameters of medium tailing were replaced by the parameters of clogging materials. The results after analyzing the dam stability are listed in table 5. From table 5, we can study, regardless of the ordinary method, the Bishop simplified method or Janbu simplified method, that the stability coefficient after clogging is smaller than before clogging and also it shows that the chemical clogging can influence the safety and stability of the tailing dam and the trend to reduce the direction.

In fact, chemical clogging occurs in a part of medium tailing area so the actual safety coefficient is higher than for the model, but it is still lower than in the case of chemical clogging.

CONCLUSION

Through the indoor soil test and mathematical model analysis, we study:

(1) Ferrous iron in water(PH=9.5-10.3) is constantly in contact with the air and produces a series of reactions such as oxidation, eventually becomes a blocking substance with $Fe(OH)_3$ as the main clogging component.

(2) The chemical clogging substances mainly include $Fe(OH)_3$, some cements and strong adsorption humus groups that will jam the pore channels and absorb the ions or tailings in water to form a larger group that accumulate in porous media and drain mouths will result in poor seepage and affect its permeability.

(3) The surface roughness of the tailings increases after the chemical clogging, moreover, the chemical clogging reduces the material migration ability of the porous media, so it also makes the density of the tailings per unit volume increase. Finally, this may cause an increase in the internal friction coefficient.

(4) The chemical clogging can reduce the stability of tailing dam.

(5) Complex chemical environment is the precondition of the chemical clogging, so strengthening monitor on the water environment of

tailing dam will contribute to the study on the stability of tailing dam.

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АНАЛИЗ НА ВЛИЯНИЕТО НА ХИМИЧЕСКОТО ЗАДРЪСТВАНЕ И ПРОСМУКВАНЕ ВЪРХУ СТАБИЛНОСТТА НА ХВОСТОХРАНИЛИЩАТА

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(Резюме)

Устойчивостта на стените на хвостохранилищата има много важно значение за околната среда, 1овешкия живот и сигурност. Химичните процеси в хвостохранилището, като утаяване и кристализация произвеждат много химични вещества, които могат да запушат порите на каналите (т.е. задръстване с тиня). По този начин се влияе на режима на изтичване на хранилището и се застрашава безопасността му. В специфичната хидрохимична обстановка микроструктурите са важен фактор за безопасността на хранилището, а макро-явленията (поддаване или скъсване на стената) се отразяват на микро-структурата. В тази работа се анализират химичните ефекти във взаимодействието вода-почва, свързващата роля на микроструктурата, на взаимодействието вода-хвост, както и ефектите върху физични и механични параметри, като коефициента на проницаемост, обемната плътност, кохезия и пр.. В резултат на всичко това се прави анализ за стабилността на хвостохранилището.