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Slake Durability of a Deep Red Stratum Sandstone under Different Environments

Jianfeng Qi, Wanghua Sui
School of Resources and Geosciences, China University of Mining and Technology, qijianfeng@cumt.edu.cn

Abstract This paper presents an experimental investigation on the slake durability of a deep Jurassic red sandstone under different environments. The environments considered in a series experiments include temperature, water spraying-air drying and water saturating-oven drying. The results show that only small debris avalanche down with alternative change in temperature. Flaking of sand particles under 0.25 mm and small slaking cracks appear progressively with water spraying and saturating. The air and oven drying processes increase the cracks and sand particles obviously. Among the different factors, water is the most direct influencing factor on the sandstone slaking, and the alternative change of temperature exacerbates the slake. It is concluded that the mechanisms of slaking of red sandstone include the water-splitting slaking, the drying dehydration shrinkage cracking and the dissolving slaking.
Keywords red stratum sandstone, slake durability, environment, rock water interaction

Introduction

Red stratum mainly refers to the red sedimentary rock formation of Triassic, Jurassic and Cretaceous Systems, which is always exposed during the construction of shaft and tunnel in coal mines. It is easily softened and slaked with water, which frequently affects the safety of engineering. Sui (1991) and Feng et al. (1994) did a preliminary study on the main hydrological and engineering geological problems in shaft building within the red stratum. Franklin and Chandra (1972) established a method of a standard cycle of drying and wetting for determining the slake durability index and proposed a classification of soil and rock slake durability. Yamaguchi and Yoshida (1988) studied the slake durability of the rock associated with rock absorbing water and their environmental temperature. Erguler et al. (2009a, 2009b) studied on the slake durability of clay rocks in different climatic conditions and put forward a new durability classification chart with resistant slaking of rocks. There are different changes of environments with various engineering. It is found that the rock has a different slaking under different environments. Comprehensive and comparative studies focusing on that with precise test have great significance for construction. However previous studies have not paid much attention to it. This paper presents the slake durability characteristics of a deep Jurassic red stratum sandstone with a series of tests under different environments. The influencing factors and mechanisms in the slaking process are also studied combined with the analysis of chemical compositions, mineral compositions and aqueous solution.

Samples and methodologies

Samples

The red stratum sandstone samples were taken from a coalmine construction in buried depth of 164.04~167.06 m in Shandong Province, China. Table 1 lists the rock chemical compositions which were analyzed by atomic absorption spectrometry.

Table 1 *Chemical composition of a red stratum sandstone (%)*

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	MnO	TiO_2	FeO	P_2O_5	Loss on ignition
58.41	9.42	3.08	11.72	0.80	1.88	1.54	0.27	0.52	1.68	0.10	10.59

Table 2 lists the mineral compositions which were analyzed by X-ray diffraction. The results show that main clay minerals are montmorillonite, illite and chlorite. Clay minerals are the main factor influencing the slake durability of rocks (Liu and Lu 2000). And the other minerals mainly include quartz, calcite and a certain amount of feldspar and hematite.

***Table 2** Mineral composition of a red stratum sandstone (%)*

Clay minerals			Other minerals			
Montmorillonite	Illite	Chlorite	Feldspar	Calcite	Quartz	Hematite
15	10	10	7	25	31	2

Methodologies

Slaking of the red stratum sandstone is related to the environment. In order to study the slake durability under different environmental conditions, the following tests are carried out:

a. Slake durability index test. The index is determined by a standard drying and wetting cycle test. The morphological changing of the rock samples was observed. A slake durability classification after Franklin and Chandra (1972) was given.

b. Alternating hot-cold cycles test. The rock slaking characteristics was investigated under different temperature conditions, including drying with a oven temperature of 105 ℃ for 12 hours and then put it in a room temperature of 16 ℃ for 12 hours as a test cycle.

c. Water spraying-air drying cycles test. The rock sample was soaked with spraying water, and air dried indoor for 72 hours or more, then the slaked sample was sieved. At the same time the slaking characteristics were observed during the process. The cycle was repeated at least eight times. This test is designed to simulate the rocks during the process of excavation in the tunnel or shaft construction.

d. Water saturating-oven temperature drying cycles test. The rock samples were immersed completely in pure water for 24 hours and observed carefully. Then the samples were dried in an oven with a temperature of 105 ℃, sample's status were observed and described. The samples were sieved and aqueous solutions were analyzed. The cycle was repeated at least eight times.

Results and analysis

Slake durability index and shape changes

The slake durability index (second cycle) is calculated as the percentage ratio of final to initial dry sample weights as follows (Franklin and Chandra 1972):

Slake durability index $I_{d2} = \frac{C-D}{A-D} \times 100\%$

where A is the weight of the drum plus initially rock samples; C is the weight of the drum plus retained portion of the samples after second cycle; D is the weight of the drum which is brushed clean.

The slake durability index of the deep red stratum sandstone is calculated to be I_{d2}=72.56%, and its slake durability is "medium", that means its slake durability cannot be ignored in engineering. Its slake durability in the process of engineering construction should be considered. Fig. 1 shows the rock morphological changes with the slake durability index test cycles. The size of rock samples decreases and the rock grinding roundness increases under the mechanical disturbance.

(a) initial *(b) the 2nd cycle* (c) *the 5th cycle*

***Fig. 1** Shape changing of rocks with the slake durability index cycles test*

Temperature

Fig. 2 shows the temperature effect on the rock slaking characteristics. The main body of the sandstone keeps stable. There only small debris avalanche down from the rock surface after 5 alternative hot-cold cycles test. Temperature change leads to the expansion and contraction of rocks.

(a) initial *(b) the 2nd cycle* (c) *the 5th cycle*

Fig. 2 *Rock performance with the alternative hot-cold cycles test*

Water

Water is the main factor in the softening and slaking process of the sandstone. Fig. 3 shows the slaking process characteristics with water spraying-air drying test. After water spraying 20 minutes, the rock surface becomes soft. Sand particles slake off obviously when touching the sandstone surface as shown in Fig. 3 (b). Fig. 3 (c), after indoor air drying for more than 72 hours, flaking of sand particles under 0.25 mm and small slaking cracks appear progressively. Fig.4 shows the change of particles in mass with water spraying-air drying test cycle (Initial rock samples total mass is 549.83 g).

(a) initial water spraying *(b) weting-surface softening* *(c) dring-spalling and slaking*

Fig. 3 *Rock performance with the water spraying-air drying test*

Water and Temperature

The slaking characteristics are more obvious and stronger under the condition of water saturating-oven temperature drying cycle test than water spraying-air drying test. Fig. 5 shows the changing of particles in mass with water saturating-oven temperature drying test cycle (Initial rock samples total mass is 228.87 g). It is mainly flaked into sand particles under 0.25 mm and other sizes particles are also increased significantly with the test cycle.

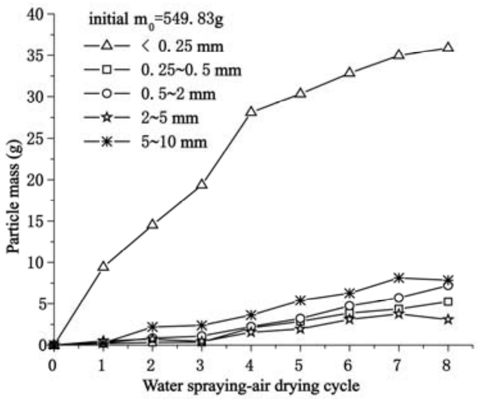


Fig. 4 *Particles change in mass during water spraying-air drying cycles slaking test*

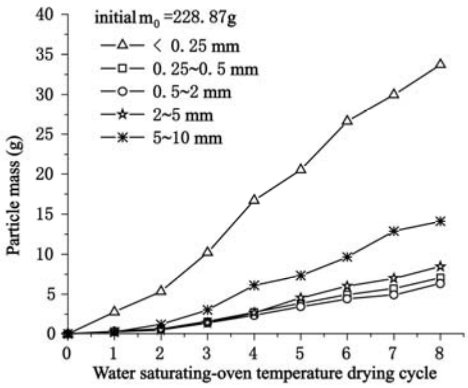
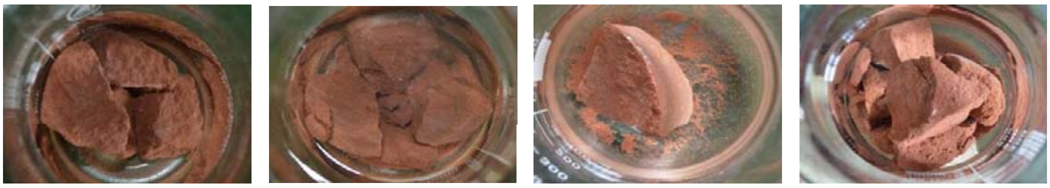


Fig. 5 *Particles change in mass during water saturating-oven temperature drying cycles slaking test*

Fig. 6 shows the process of gradual slaking process of rock samples with water saturating. A slight slaking appears first and sand particles flaks from the rock surface after 2 hours in water. And it has varying degrees of slaking and cracks in each water saturating cycle. The clay minerals have great expansion with water. Therefore, hydrated expansible slaking of the red stratum sandstone mainly relates to the distribution and contents of clay minerals.



(a) initial in water *(b) slight slaking and sand particles flaking* *(c) slaking and cracks*

Fig. 6 *Rock performance with water saturating*

Simultaneously the oven temperature drying process exacerbated the rock slaking. Fig. 7 shows the rock changing with the test cycles, and the rock samples become crushing. The drying process is a process of rock dehydration, the uneven dehydration shrinkage lead to the rock cracking and slaking.

(a) the 1st cycle *(b) the 2nd cycle* *(c) the 5th cycle* *(d) the 8th cycle*

Fig. 7 *Rock performance after water saturating with oven temperature drying cycles test*

Table 3 lists the results of pH and ion concentration analysis with aqueous solution at different cycles during slaking process. The ion concentrations of Na^+, Ca^{2+}, Mg^{2+}, SO_4^{2-} and CO_3^{2-} changed obviously. It implied that there are mineral dissolving or a corrosion of mineral composition during the interaction between red stratum sandstone and water.

Table 3 *Ion concentration and pH of the solution due to the slaking of rock*

Sample	Cation (mg/L)									Anion (mg/L)		pH
	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	Fe^{3+}	Mn^{2+}	Ti^{4+}	V^{5+}	SO_4^{2-}	CO_3^{2-} /HCO_3^-	
Initial	0	0	0	0	0	0	0	0	0	0	0.0149	6.615
The 4th cycle	4.9876	35.115	12.756	2.9642	0.0733	0.0903	0.0005	0.0009	0.0059	53.000	43.467	8.076
The 8th cycle	5.0399	38.923	15.432	3.3627	0.0322	0.0592	0.0014	0.0011	0.0077	97.000	25.805	8.154

Conclusions

This study focused on the slake durability of a deep red stratum sandstone under different environments. The main conclusions are as follows:

The slake durability index of the deep red stratum sandstone is I_{d2}=72.56%, the slake durability is “medium”. Its slake durability must be considered in the process of shaft building or coal mining.

Water is the most direct influencing factor on the sandstone slaking. The alternative change of temperature exacerbates the rock slake. Adopting measures to keep away water is the key to avoid the red stratum sandstone softening or slaking for the engineering safety.

With the analysis of various slaking tests, mineral composition and aqueous solution, the slake durability mechanisms of red stratum sandstone can be described as three aspects: the water-splitting slaking, the drying dehydration shrinkage cracking and the dissolving slaking.

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References

Erguler ZA, Shakoor A (2009) Relative contribution of various climatic processes in disintegration of clay-bearing rocks. Engineering Geology 108: 36-42

Erguler ZA, Ulusay R (2009) Assessment of physical disintegration characteristics of clay-bearing rocks: Disintegration index test and a new durability classification chart. Engineering Geology 105: 11-19

Franklin JA, Chandra R (1972) The slake-durability test. International Journal of Rock Mechanics and Mining Sciences 9: 325-341

Feng QY, Sui WH, Han BP, Cao DT (1994) The main hydrogeological and engineering geological problems in shaft construction and exploitation in red beds. Coal Science and Technology 22(9): 45-49

Liu CW, Lu SL (2000) Research on mechanism of mudstone degradation and softening in water. Rock and Soil Mechanics 21(1): 28-31

Sui WH (1991) Instability characteristics of red mudstone with water and shaft construction practices. Coal Geology & Exploration 1: 41-45

Yamaguchi H, Yoshida K (1988) Slaking and shear properties of mudstone. Rock Mechanics and Power Plants 24(3): 133-144