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Combined Effect of Load and Water Environment on Creep Behaviours of Red Sandstone

To cite this article: Chaoyun Yu and Chunan Tang 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **283** 012003

Combined Effect of Load and Water Environment on Creep Behaviours of Red Sandstone

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Abstract. Creep experiment was conducted on specimens submerged in water to know the combined effect of load and water on mechanical behaviour of red sandstone. Compared with saturated and dry specimen with the sealed surface, results show that the steady-state creep strain rate of submerged specimen is the highest, whereas, the corresponding long-term strength is the smallest. Creep cracks initiation and propagation make it possible for water in the environment to migrate into the tip of new cracks, which intensifies the stress corrosion effect of water. This is the effect mechanism of a combined action of load and water on the creep behaviour of red sandstone. The presented experimental results are beneficial for monitoring and assessing the long-term stability and safety of rock engineering.
Keywords: rock mechanics; creep tests; water-rock interaction; long-term strength.

1. Introduction

Water has a significant effect on the physical and mechanical properties of rock, and it is often an important cause of instability and failure of rock mass engineering structures. In hydraulic engineering, most of large-scale sliding often occurs due to impounding and rainfall [1-3]. In mining engineering, the pillars of abandoned mine occurs failure caused by the rise of groundwater level, resulting in roof falling and surface subsidence accidents [4]. Despite a large number of current research achievements on the influence of water on rock mechanical properties, however, from the perspective of test method, most of them focused on the rock specimens with sealed surface, thus it ignores the fact that whether the reservoir bank slope or the mining pillar suffers the effect of not only load but also water environment. At present, the creep experiments to obtain the creep mechanical parameters of rock specimens under the combined action of the continuous load and water environment are relatively few. Thus, it is necessary to study the issue and the test results would provide certain reference significance for assessment of long-term stability of rock mass engineering.

2. Material and Test Methods

The rock materials used in the test are red sandstone. Cylindrical samples 50 mm in diameter and 100 mm in height are prepared by drilling from the same block. Average specific gravity, dry unit weight and porosity were 2.54, 22.2 kN/m^3 and 12.6%, respectively. Natural water content was 2.6 ~ 2.9%.

Before the creep test, the red sandstone specimens in different state are tested for basic physical and mechanical property with the machine RMT-150C. The term "Submerged" in Table 1 refers to the specimen saturated firstly and then submerged in a chamber filled with water during tests. The term "Saturated" refers to the specimen dried at 105 ℃ for 24 h firstly then absorbing water to a constant mass for 48 h, and its surface is sealed with waterproof material. The term "Dry" refers to the specimen dried at 105 ℃ for 24 h, after cooling, its surface is sealed with waterproof material. The

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term “Soften coefficient” refers to the ratio of the strength of the wet specimen (such as submerged and saturated) to the strength of the dry specimen.

Table 1. Mechanical parameters of submerged, saturated and dry specimens.

Specimen state	σ_c /MPa	E /GPa	v	Soften coefficient (R_c)
Submerged	53.7	9.1	-	0.50
Saturated	55.5	10.9	0.38	0.52
Dry	106.7	16.9	0.26	-

The main part of the test is to make uniaxial compression creep experiment on submerged specimens. As a comparison task, the dry and saturated specimens, whose surface are sealed, are also tested to know the combined effect of water and load on creep behaviours of rock. In order to obtain the typical three creep stages at laboratory scale, the stress levels applied on each specimen ranges from about 75~95% σ_c, as shown in Table 2.

3. Test Results

Figure 1a-1c show the creep curves of submerged, saturated and dry specimens, respectively. It can be seen that the axial strain of the specimen increases with time at each constant stress, and the ultimate instability failure occurs. With the increase of stress, the failure time of the specimen decreases. As can been seen in Table 2, the failure of submerged specimen is earlier than the saturated and dry specimen under the same conditions. For example, at the same stress level of 80%, the time to failure of the submerged specimen is 17.79 h, 21.87 h for saturated specimen and 51.43 h for dry specimen.

Table 2. Creep test results of submerged, saturated and dry specimens.

Specimen state	Stress level /%	Steady strain rate /h^{-1}	Time to failure /h	Long term strength /MPa
Submerged	75	0.012	48.72	40.58 (75.6% $\sigma_{c(sub)}$)
	80	0.050	17.79	
	85	0.222	5.21	
	90	1.194	0.58	
	95	6.287	0.11	
Saturated	77	0.013	-	44.44 (80% $\sigma_{c(sat)}$)
	80	0.034	27.18	
	87	0.202	3.84	
	92	0.870	1.08	
	97	1.195	0.57	
Dry	80	0.008	51.43	83.03 (77.8% $\sigma_{c(dry)}$)
	86	0.028	20.94	
	90	0.104	7.44	
	95	1.491	0.22	

Figure 2 shows the relationship between steady-state strain rate and stress level under semi logarithmic coordinates. It can be seen that the strain rate of the specimen increases with the increase of stress level. It is noteworthy that at the same stress level of 80%, the axial stress of the immersed specimen is 0.050 /h, which is 1.5 times the strain rate of the saturated specimen (i.e., 0.034 /h), and 6.3 times the strain rate of the dry specimen (i.e., 0.008 /h).

Figure 3 shows that the rock strength decreases with the extension of stress action time and the law can be expressed by an empirical exponential equation. The long-term strength of submerged, saturated and dry specimens are 40.58 MPa, 44.44 MPa and 83.03 MPa, respectively, which are 75.6%, 80% and 77.8% of uniaxial compressive strength under corresponding conditions. Therefore, the long-term strength of the submerged specimen is the smallest. It indicates that the long-term strength of red sandstone is further weakened under the combined action of load and water.

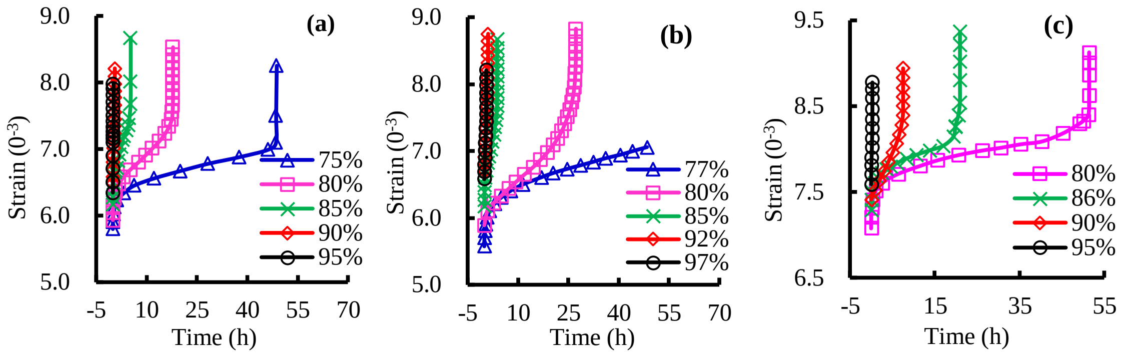

Figure 1. Creep curves of submerged, saturated and dry specimens.

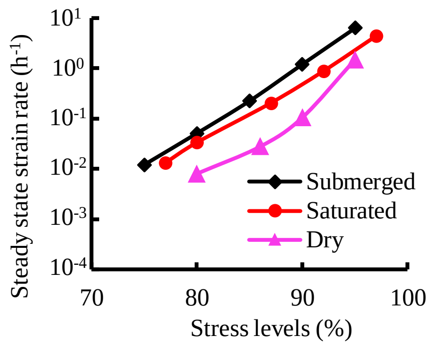

Figure 2. Relationship between steady state strain rate and stress level.

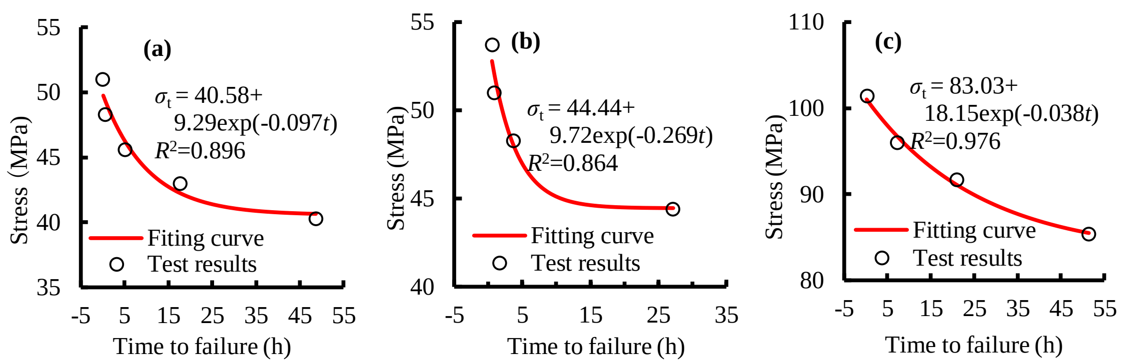

Figure 3. Long-term strength of submerged, saturated and dry specimens.

4. Discussion

According to the mentioned above, it is interesting to find that the creep behaviour of saturated specimen is different when the environment is changed. When the specimen is submerged in water with surface in contact with water, its creep strain rate is larger, its long-term strength is smaller than that of specimen with sealed surface. What is the effect mechanism to explain the above results?

A test was made to observe the changes of water content before and after applying constant stress level with different creep time. The experimental procedure is: (1) Four saturated specimens were selected randomly and their initial saturation water content (ω_1) is recorded; (2) Creep test is conducted on each saturated specimen at the same constant stress level of 80%; (3) Keeping the stress level constant for 0 h, 5 h, 10 h and 20 h, respectively, then unloading it; (4) Each specimen after creep test is saturated again in a vacuum saturation device, and the new water content (ω_2) of the saturated specimen is also recorded. A variable α is introduced for conveniently describing the relationship between the change of water content and creep test period. The term α refers to the ratio of ω_1 to ω_2.

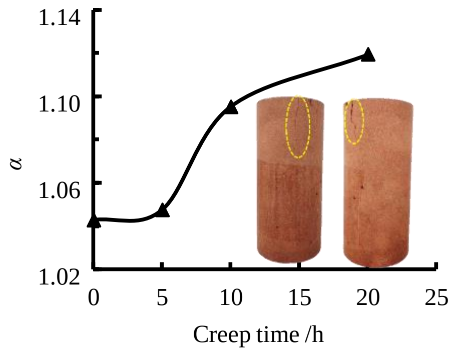

Figure 4. Relationship between the variable α and creep time.

Figure 4 shows the relationship between variable $\boldsymbol{\alpha}$ and test time. It can be seen that the longer the creep time, the greater the value of variable $\boldsymbol{\alpha}$. Compared with t = 0 h, the variable $\boldsymbol{\alpha}$ increased by 0.4 %, 5.02 % and 7.3 % when t = 5 h, 10 h and 20 h, respectively.

The change of $\boldsymbol{\alpha}$ indicates the change of water absorption characteristics of rock, which can reflect the change of cracks distribution inside the rock. Heap et al. [5] has proved that there is a corresponding relationship between the acoustic emission activity in rock and the crack growth in various creep stages. Creep crack propagation of rock materials occurred in the latter two stages of creep process, namely, steady-state creep stage and accelerated creep stage. In Figure 1, when t = 5 h, the specimen is in the first transient creep stage with cracks opening but not growth; when t = 10 h, the specimen is in the second creep stage with cracks stable growth; when t = 20 h, specimen is in the third accelerating creep stage along with unstable crack propagation, and there are visible cracks on the surface of specimen as shown in the lower right of the figure. This is the reason why the variable $\boldsymbol{\alpha}$ shows little change when the creep time changes from t = 0 h to t = 5 h, but it changes significantly when the time is 10 h and 20 h.

The test results are a further evidence that creep is a process of internal new crack initiation and growth [6]. For submerged specimen, its surface is in contact with water. When creep occurs and is accompanied by crack initiation and growth, it makes it possible that the water in the environment migrates into the tip of new cracks, which intensifies the stress corrosion of water. This is the reason why the long-term strength of the submerged specimen is smaller than that of the saturated specimen with sealed surface.

The test method on submerged specimen in this paper can fully reflect the combined effect of water and load on rock mechanical properties, therefore, the test results is useful for refining creep model and explaining influence mechanism on the deformation and stability of rock mass engineering affected by water. For example, Liu et al. [7] found that microseismic activity was detected in the right bank slope after the initial impoundment by the microseismic monitoring system without construction disturbance. According to conclusions of the research, the reason could be that the long-term immersion action changes the mechanical properties of rock mass, which reduces the bank slope stability. Therefore, it is suggested that long-term monitoring of the rock engineering affected by water and appropriate reduction of long-term mechanical parameters will be needed to limit severe rock

IOP Conf. Series: Earth and Environmental Science **283** (2019) 012003 doi:10.1088/1755-1315/283/1/012003

engineering disasters.

5. Conclusion

The creep mechanical properties of red sandstone submerged in water are obviously strengthened, which is manifested in the reduction of long-term strength and the shortening of failure time. The creep of rock is accompanied by cracks initiation and growth, and water continuously migrates into the tip of cracks in submerged specimen, which aggravates the physical and mechanical effect of water on rock. This is the reason why the creep characteristics of the submerged specimen are more obvious than that of the saturated specimen with sealed surface. Adjusting properly the related parameters obtained by conventional test method is needed for the long-term stability analysis of rock mass engineering.

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