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Research Article

Effect of Chemical Corrosion on the Mechanical Characteristics of Parent Rocks for Nuclear Waste Storage

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Long-term immersion was adopted to explore the damage deterioration and mechanical properties of granite under different chemical solutions. Here, granite was selected as the candidate of parent rocks for nuclear waste storage. The physical and mechanical properties of variation regularity immersed in various chemical solutions were analyzed. Meanwhile, the damage variable based on the variation in porosity was used in the quantitative analysis of chemical damage deterioration degree. Experimental results show that granite has a significant weakening tendency after chemical corrosion. The fracture toughness K_{IC}, splitting tensile strength, and compressive strength all demonstrate the same deteriorating trend with chemical corrosion time. However, a difference exists in the deterioration degree of the mechanical parameters; that is, the deterioration degree of fracture toughness K_{IC} is the greatest followed by those of splitting tensile strength and compressive strength, which are relatively smaller. Strong acid solutions may aggravate chemical damage deterioration in granite. By contrast, strong alkaline solutions have a certain inhibiting effect on chemical damage deterioration. The chemical solutions that feature various compositions may have different effects on chemical damage degree; that is, SO_4^{2-} ions have a greater effect on the chemical damage in granite than HCO_3^{-} ions.

1. Introduction

With the rapid development of industrialization, environmental problems have become worse since the 1970s. As a result, environmental geotechnical engineering research has become one of the important research topics in this field. Studying the physical and mechanical properties of rocks provides a scientific basis for the design and operation of measures to safely assess a permanent geological storage library of nuclear wastes under the corrosion of chemical solutions.

The construction of the nuclear waste disposal repository is a lengthy, arduous, and complex strategic task. Therefore, national governments have invested huge manpower, material, and financial resources for research. In addition, the governments selected rocks with different lithology as natural barriers for nuclear waste disposal repositories owing to the differences in geological conditions found in each country. Various geological rock masses have distinct physical and mechanical properties. Granite is widely distributed and is basically characterized by its stable performance. Thus, it is often selected for the underground disposal laboratory by many countries.

Rock mass, which is distributed in repositories of nuclear waste disposal plants, is often affected by the temperature field, stress field, seepage field, groundwater, and so forth; in studying, these researchers need to consider the coupling effect on thermohydrological, hydromechanical (HM), thermomechanical, and thermohydromechanical (THM) couplings [1–3]. Many international scholars have launched a series of studies [4–9]. For example, Millard et al. [4] adopted numerical simulation to analyze the surrounding rock of a near field repository of nuclear waste disposal based on THM and found that although temperature is almost not influenced by the THM coupling, stress is greatly affected. Blum et al. [5] used "Udec" to examine the coupling properties of HM of the far field repository of nuclear waste disposal in the fractured rock mass. Meanwhile, Zhang [6] employed their own development program and adopted the coupling model of THM to analyze the FEBEX in situ test from the two-dimensional finite element. Their results show that the physical and mechanical properties of the rock mass surrounding the disposal are influenced by stress, seepage, and temperature fields.

During the service life of rock engineering projects, the influence of the surrounding hydrochemical environment is nonnegligible, along with that of the external load. The influence of the hydrochemical environment on the mechanics of rocks has been intensively studied in recent years, and several accomplishments have been achieved. Atkinson [7, 8], Martin [9], Charles [10], and Freiman [11] all studied the influence of different chemical solutions on the crack tip of the Si–O bond. Lawn et al. [12] systematically studied the chemical function of stress corrosion on the surface and reported the extension of the Kia critical crack by the stress corrosion. Atkinson and Meredith [13] investigated the influence of different aqueous chemical solutions on the strength and crack propagation rate of quartz and found that higher concentrations of OH^- ion result in a faster expansion rate of the quartz fracture; meanwhile, the flow solution has a certain control effect on the crack growth rate. Kirby [14] studied the effect of chemical solutions on rocks from the interaction of water, rock, and humidity; the influence of chemical corrosion; and the time effect of chemical corrosion and water pressure. Bulau et al. [15–18] studied the effect of water-rock dissolution on the crack propagation of rocks. Lajtai et al. [19] analyzed and discussed the influence of water on the mechanical features and failure of granite. Dunning et al. [20] explored the effect of chemical environment on the toughness value and crack propagation rate of rock fractures. Ning et al. [21] established a chemical damage strength model for acid solutions based on the corrosive effect of different acid solutions on the cementing materials of sandstones.

General nuclear wastes, which are buried deep in the 500–1000 m geological body from the surface, are isolated from the human survival environment and are permanently hidden through a multiple barrier system. The stress field of surrounding rocks greatly changes after excavation, which intensifies the degree of internal damage in the surrounding rock mass near the field geological repository. Microcracks, crevices, and flaws of different orders are inevitably scattered inside rocks as various types of natural aggregates form during the geologic process.

Rock failure is closely related to rock fracture. A number of scholars have applied fracture toughness to the quantitative evaluation of rock engineering stability and safety and have conducted a considerable number of experimental studies. Ciccotti et al. [22] and Saadaoui et al. [23] adopted the double torsion method to experimentally study the static fracture toughness of rocks. Cui et al. [24] comparatively analyzed two test methods for the fracture toughness of chevron-notched rocks. Ayatollahi and Aliha [25] conducted an experimental study of the fracture toughness of brittle rocks under I/II mixed-load modes. Chen and Zhang [26] investigated the fracture toughness of rocks sampled from deep strata by a laboratory test. Erarslan and Williams [27] explored the relationship between the rock fatigue failure mechanism and rock fracture toughness in their study. Apart from the above, deterioration damage in crack rocks in different hydrochemical environments have also drawn great attention from scholars, especially those studying fracture toughness and their rock correlations. However, researches on these topics have rarely been reported in the literature.

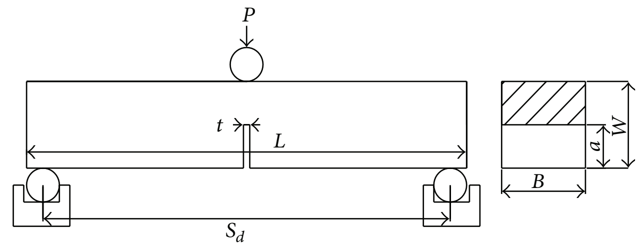


Figure 1: Loading sketch of the three-point bending specimens.

The current study conducts several experiments, including three-point bending, uniaxial compression, and tensile splitting strength tests, on Mode-I cracked sandstone specimens under different chemical corrosions. Variation regularities in the physical and mechanical properties, such as P-wave velocity, porosity, fracture toughness K_{IC}, compressive strength, and splitting tensile strength, of rocks damaged by different chemical solutions are also examined. The main findings of this study shall serve as a decision-making basis for the design and safe operation of the nuclear waste storage library.

2. Introduction of Tests

The granite used in the test was sampled from the hydrofluctuation zone at a typical bank slope located in the Three Gorges Reservoir Region, where the granite featured high homogeneity and integrity. As required by the test procedures [28], rectangular specimens with straight incisions were selected and the three-point bending method was adopted to measure the fracture toughness of the rocks (K_{IC}). Figure 1 shows the loading diagram. The cross-sectional area was 50 mm × 50 mm, the length was 250 mm × 260 mm, the depth of the straight incision was 21 mm × 23 mm, and the width was 1.0 mm. After processing the specimens, the P-wave velocities of the specimens were measured. The discrete-type specimens were screened out. A total of 68 granite specimens were selected and divided into 17 groups, one of which was used to measure fracture toughness and other related mechanical characteristics of granite under normal conditions. The measurements were used as the initial values for comparative analysis. The remaining 16 groups were employed in the experimental study on a different kind of chemical corrosion.

Before the test, the granite specimens were dried at 105°C to maintain a constant weight and then cooled for mass measurement. The vacuumization method was subsequently adopted to saturate the specimens with 0.01 mol/L of Na_2SO_4 (pH = 3.0) solution, 0.01 mol/L of NaOH (pH = 12.0) solution, 0.01 mol/L of $NaHCO_3$ (pH = 3.0) solution, and distilled water at pH = 7.0. The chemical solutions used to immerse

Figure 2: Sketch map of the acoustic wave detector RSM-SY5.

the specimens should exceed the top of the specimens by 5 cm. The specimens were taken out every month to measure the P-wave velocity and test the fracture toughness. The chemical solutions were exchanged every month. The chemical corrosion time was set to 0, 1, 2, 3, and 4 months, and 4 tests were conducted in parallel for each chemical solution under each test.

To study the relationship between the fracture toughness of specimens and their compressive or splitting tensile strength, several actions were carried out. These procedures included the following: the errors arising out of specimen heterogeneity were reduced, the comparability between the fracture toughness of specimens and their compressive strength or splitting tensile strength was improved under the same conditions, and the two segments of the fractured specimen were processed into a 100 mm rectangular specimen for the uniaxial compression test and into a cylinder specimen with a diameter of 50 mm and a length of 30 mm × 35 mm for the splitting tensile strength test. The physical and mechanical parameters of the specimens were then tested in saturation to further explore the variation regularity.

3. Test Results and Analysis

3.1. Variation Regularity in Porosity and P-Wave Velocity. The P-wave velocity of granite specimens are measured using the acoustic wave detector RSM-SY5 developed by the Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan, China. The sketch map of RSM-SY5 sound wave detector is shown in Figure 2. The porosity of specimens is measured by the saturated buoyancy weighing method.

At the beginning of the test, the P-wave velocities and porosities of the saturated granite specimens were measured every month to identify the effects of the different chemical solutions on the physical properties of the specimens. The physical variables that indicated the status of the granite specimens, which included porosity change rate [(porosity after freezing and thawing cycles − initial porosity)/initial porosity] and P-wave velocity change rate [(P-wave velocity at the initial drying − P-wave velocity after freezing and thawing cycles)/P-wave velocity at the initial drying], were defined. The porosity and P-wave velocity change rates of the granite specimens under various chemical solutions at different chemical corrosion times were determined, as shown in Figure 3.

Figure 3 implies that the physical properties of the granite specimens show the same variation trend under different chemical solutions. With the increase of chemical corrosion time, the porosity of the granite specimens gradually increased, whereas the P-wave velocity gradually decreased. Both the porosity and P-wave velocity change rates of the specimens increased as chemical corrosion time increased.

Differences existed in the porosity and P-wave velocity of the granite specimens under different chemical solutions. The porosity and P-wave velocity change rates of the granite specimens were the highest when they were immersed in the 0.01 mol/L Na_2SO_4 (pH = 3.0) solution, rated the lowest when they were submerged in the strong alkaline 0.01 mol/L NaOH (pH = 12.0) solution, and ranked in the middle when they were submersed in distilled water. Hence, the acid solution aggravated the chemical damage deterioration of the granite specimens. However, the strong alkaline solution had a certain inhibiting effect on the chemical damage of the specimens.

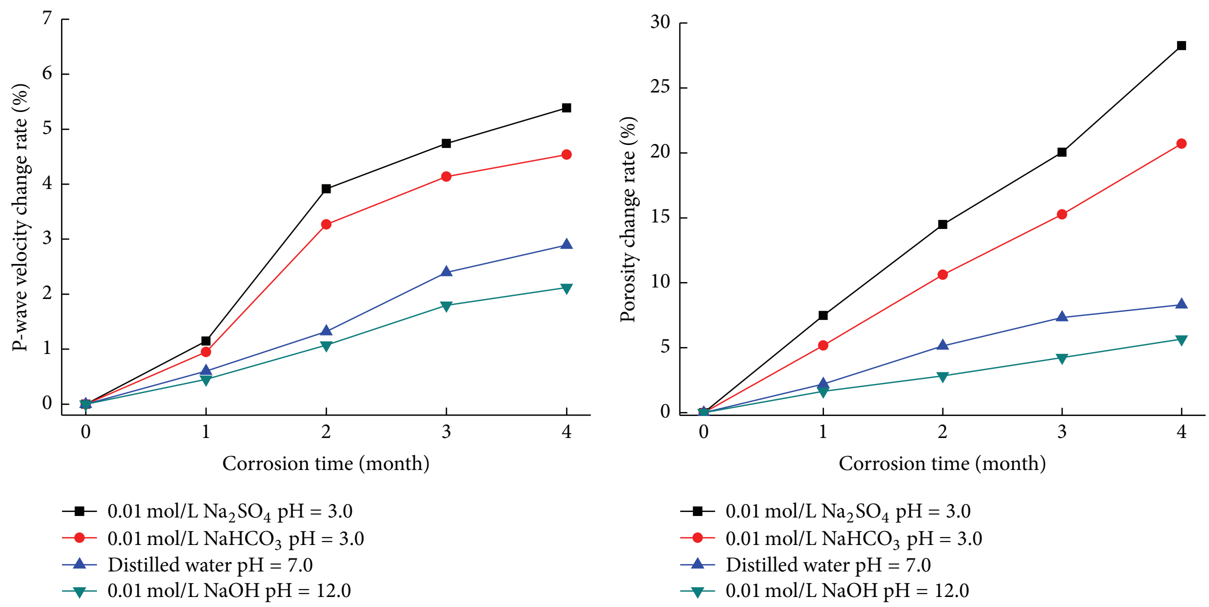
Figure 3 also demonstrates that various chemical solutions might have distinct effects on the physical damage in the granite specimens. The effect of the 0.01 mol/L Na_2SO_4 (pH = 3.0) on the porosity and P-wave velocity of the granite specimens was greater than that of the 0.01 mol/L $NaHCO_3$ (pH = 3.0) under the same conditions, thus indicating that $SO_4{}^{2-}$ ions aggravated the chemical damage in the specimens.

Figure 4 shows the relationship between the porosity and P-wave velocity of the granite specimens under different water chemical solutions. The diagram illustrates that the porosity of the granite specimens increased under various water chemical solutions, whereas the P-wave velocity showed a gradually deteriorating trend. Therefore, the consistency of both properties was significant, indicating that the P-wave velocity of granite specimens after being chemically corroded could be used to indirectly reflect the porosity change rate.

3.2. Test Result Analysis of the Fracture Toughness K_{IC} of the Granite Specimens. The fracture toughness of the granite specimens under different conditions was calculated on the basis of the K_{IC} computational formula specified in the Rock Test Procedure for Water Resources and Hydropower Engineering [28]. Figure 5 shows the relationship between the K_{IC} of the granite specimens and chemical corrosion time under different water chemical solutions. The computational formula of the fracture toughness K_{IC} is expressed as follows:

$$K_{IC} = 0.25\frac{S_d}{B}\frac{P_{max}}{B^{1.5}}y\left(\frac{a}{B}\right),$$
$$y\left(\frac{a}{B}\right) = \frac{12.75\,(a/B)^{0.5}\left[1 + 19.65\,(a/B)^{4.5}\right]^{0.5}}{(1 - a/B)^{0.25}}, \quad (1)$$

where K_{IC} refers to the fracture toughness (MPa·m$^{1/2}$); B denotes the specimen width (cm), which is equal to the specimen height W (cm); S_d represents the distance between two supporting points (cm); P_{max} symbolizes the load leading to the fracture failure (N); and a indicates the depth of straight



(a) P-wave velocity change rate ~ corrosion time

(b) Porosity change rate ~ corrosion time

FIGURE 3: Relationships between porosity, P-wave velocity of granite specimens, and corrosion time under different chemical solutions.

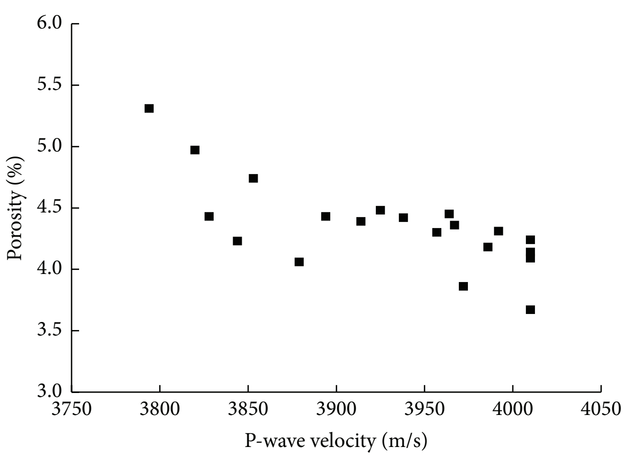


FIGURE 4: Relationship between porosity and P-wave velocity of granite specimens under different chemical solutions.

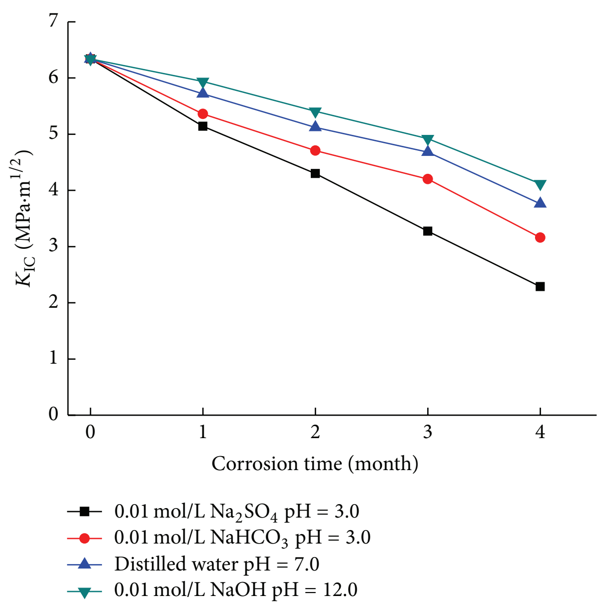


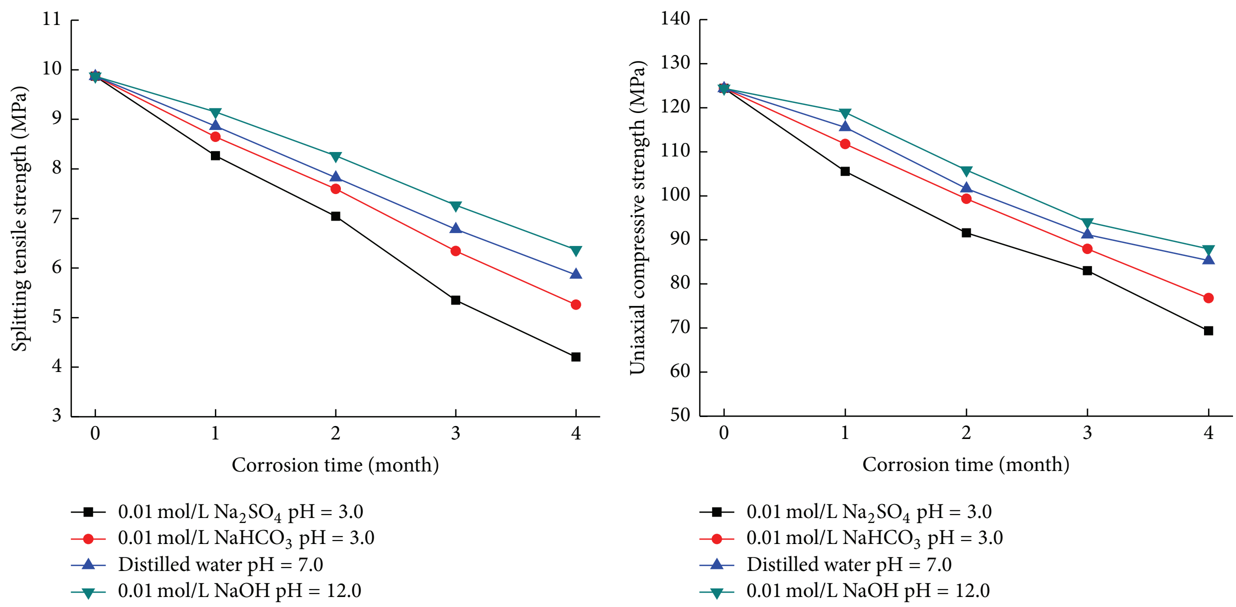
FIGURE 5: Relationship between K_{IC} of granite specimens and corrosion time under different water chemical solutions.

incision (cm). In this experiment, $S_d = 16.6$ cm, $W = B = 5$ cm, and $a = 22$ mm to 23 mm.

As shown in Figure 5, the granite specimens under different water chemical solutions showed a basically identical trend in fracture toughness K_{IC} as the chemical corrosion time increased. The fracture toughness K_{IC} of the granite specimens presented with varying degrees of deterioration after chemical corrosion. As the chemical corrosion time increased, the deterioration degree also gradually increased. Nevertheless, the degrees of deterioration shown by the granite fracture toughness differed when they were immersed in different chemical solutions.

Meanwhile, the effect of the solution pH value is presented here. The degree of deterioration of the fracture toughness K_{IC} of the granite specimens was the highest when they were immersed in the 0.01 mol/L Na_2SO_4 (pH = 3.0) solution, ranked in the middle when they were submerged in distilled water, and rated the lowest when they were submerged in the 0.01 mol/L NaOH (pH = 12.0) solution. Thus, the acid environment aggravated the deterioration of the granite specimens' fracture toughness. However, the strong alkaline environment had a certain inhibiting effect on the chemical damage deterioration of the granite.

Moreover, as shown in Figure 5, the solutions of different chemical compositions had various effects on the chemical



(a) Splitting tensile strength ~ corrosion time

(b) Uniaxial compressive strength ~ corrosion time

Figure 6: Relationships between the granite specimens' splitting tensile strength and uniaxial compressive strength as well as the chemical corrosion time under different water chemical solutions.

damage of the granite fracture toughness K_{IC}, although the acid environment aggravated the deterioration of the fracture toughness K_{IC} of the granite specimens. Under the same chemical corrosion period, the deterioration degree of the granite fracture toughness K_{IC} was lower in 0.01 mol/L $NaHCO_3$ (pH = 3.0) than in 0.01 mol/L Na_2SO_4 (pH = 3.0). Hence, SO_4^{2-} ions had a greater effect on the chemical damage of granite specimens than HCO_3^- ions.

3.3. Analysis of the Tensile and Compressive Test Results of Granite Specimens. Figure 6 shows the relationships among the granite specimens' splitting tensile strength and uniaxial compressive strength as well as the chemical corrosion time under different water chemical solutions.

As seen in Figure 6, as the chemical corrosion time increased, the splitting tensile strength and compressive strength of the granite specimens showed gradually deteriorating trends under different water chemical solutions. However, differences existed in the deterioration degrees of the splitting tensile strength and compressive strength of the specimens when they were immersed in different water chemical solutions.

When the solution concentration and pH value remained unchanged, the chemical deterioration degrees of the tensile strength and compressive strength of granite specimens were higher in 0.01 mol/L Na_2SO_4 (pH = 3.0) than in pH = 7.0 distilled water and in 0.01 mol/L NaOH (pH = 12.0). The deterioration degrees of the tensile strength and compressive strength of the granite specimens were also higher in pH = 7.0 distilled water than in the alkaline 0.01 mol/L NaOH (pH = 12.0) solution. Therefore, the strong acid solution aggravated the chemical damage deterioration of the tensile strength and compressive strength of the granite. On the contrary, in the strong alkaline environment (NaOH solution), a certain inhibiting effect existed to mitigate the chemical damage deterioration of the granite specimens.

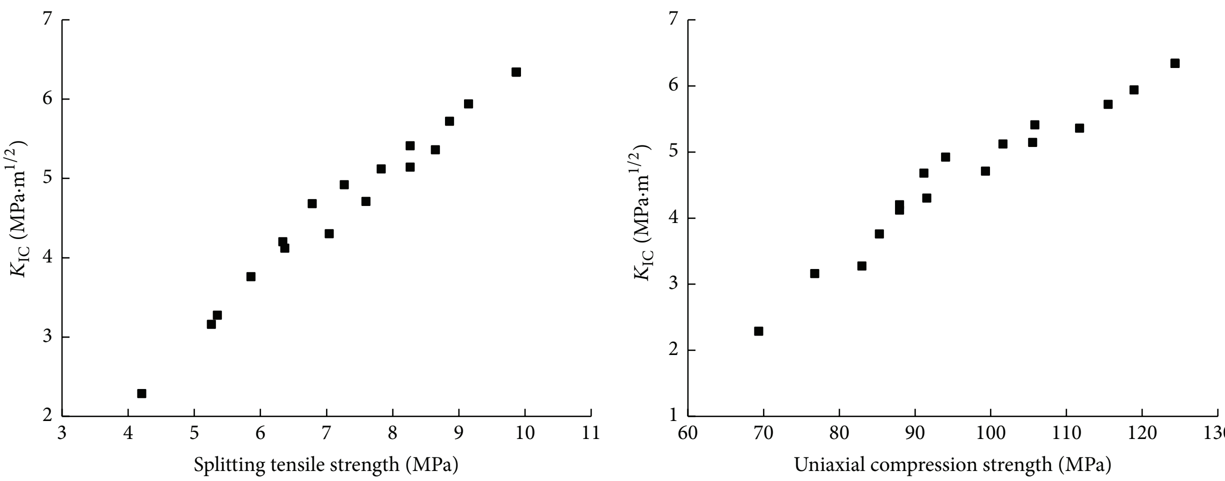
When the solution concentration and pH value remained unchanged, the chemical damage deterioration degrees of the tensile strength and compressive strength of the granite specimens were higher in the 0.01 mol/L Na_2SO_4 (pH = 3.0) solution than in the 0.01 mol/L $NaHCO_3$ (pH = 3.0) solution. Therefore, SO_4^{2-} ions aggravated the chemical deterioration degrees of the tensile strength and compressive strength of the granite specimens.

3.4. Analysis of the Relations between the Splitting Tensile Strength, Uniaxial Compressive Strength, and K_{IC} of the Granite Specimens. Previous studies have reported existing relations between the strength characteristics and fracture toughness of rocks. In the current study, the relationships between the splitting tensile strength, uniaxial compressive strength, and fracture toughness K_{IC} of the granite specimens were evaluated based on the summary of the test data in this study. The results are shown in Figure 7.

Based on the diagram shown in Figure 7, a linear relationship existed between the splitting tensile strength and K_{IC} and between the uniaxial compressive strength and K_{IC} of granite specimens that were damaged under different chemical solutions. The relations could be, respectively, expressed as follows:

$$K_{IC} = 0.6746\sigma_t - 0.2732, \quad R^2 = 0.9797, \tag{2}$$

$$K_{IC} = 0.06646\sigma - 1.8555, \quad R^2 = 0.9549, \tag{3}$$



(a) K_{IC} ~ Splitting tensile strength

(b) K_{IC} ~ Uniaxial compression strength

Figure 7: Relationship between splitting tensile strength, uniaxial compressive strength, and K_{IC} of granite specimens.

where σ denotes the uniaxial compressive strength of the granite specimens, and σ_t refers to the splitting tensile strength of the granite specimens.

To gain a better understanding of the effects of chemical solutions on the chemical damage degrees of fracture toughness, splitting tensile strength, and uniaxial compressive strength of the granite specimens, the chemical damage factor K_{cf} can be defined as follows:

$$K_{cf} = \frac{f_0 - f_N}{f_0} \times 100\%, \quad (4)$$

where f_0 denotes the mechanical characteristic value of the granite specimens under normal conditions, and f_N refers to the mechanical characteristic value of the granite specimens when they underwent N months chemical corrosion. A high K_{cf} indicates weak resistance capacity of the granite specimens against chemical corrosion.

Figure 8 shows the relationship between the deterioration rate of mechanical characteristics (including fracture toughness, splitting tensile strength, and uniaxial compressive strength of the granite specimens) and the chemical corrosion time identified based on (4) under different water chemical solutions.

Local and international scholars, such as Zhang et al. [29, 30], Golshani et al. [30–32], and Deng et al. [33, 34], have explored the relationship between fracture toughness and tensile strength of rocks. Their findings showed a linear relationship between fracture toughness K_{IC} and tensile strength of granite. Deng et al. [34] deduced a formula to explain the relationship between fracture toughness K_{IC} and tensile strength for Mode-I cracked rocks. This formula is expressed as

$$r = \frac{1}{2\pi}\left(\frac{K_{IC}}{\sigma_t}\right)^2, \quad (5)$$

where r denotes the crack propagation radius.

The findings in the literature [30–33] state that the crack propagation radius is large and small when the rock strength is high and low, respectively. In the current study, the crack propagation radius of granite specimens was analyzed under the test conditions specified here to evaluate the effects of different chemical solutions on the crack propagation radius of rocks. The results are shown in Figure 9.

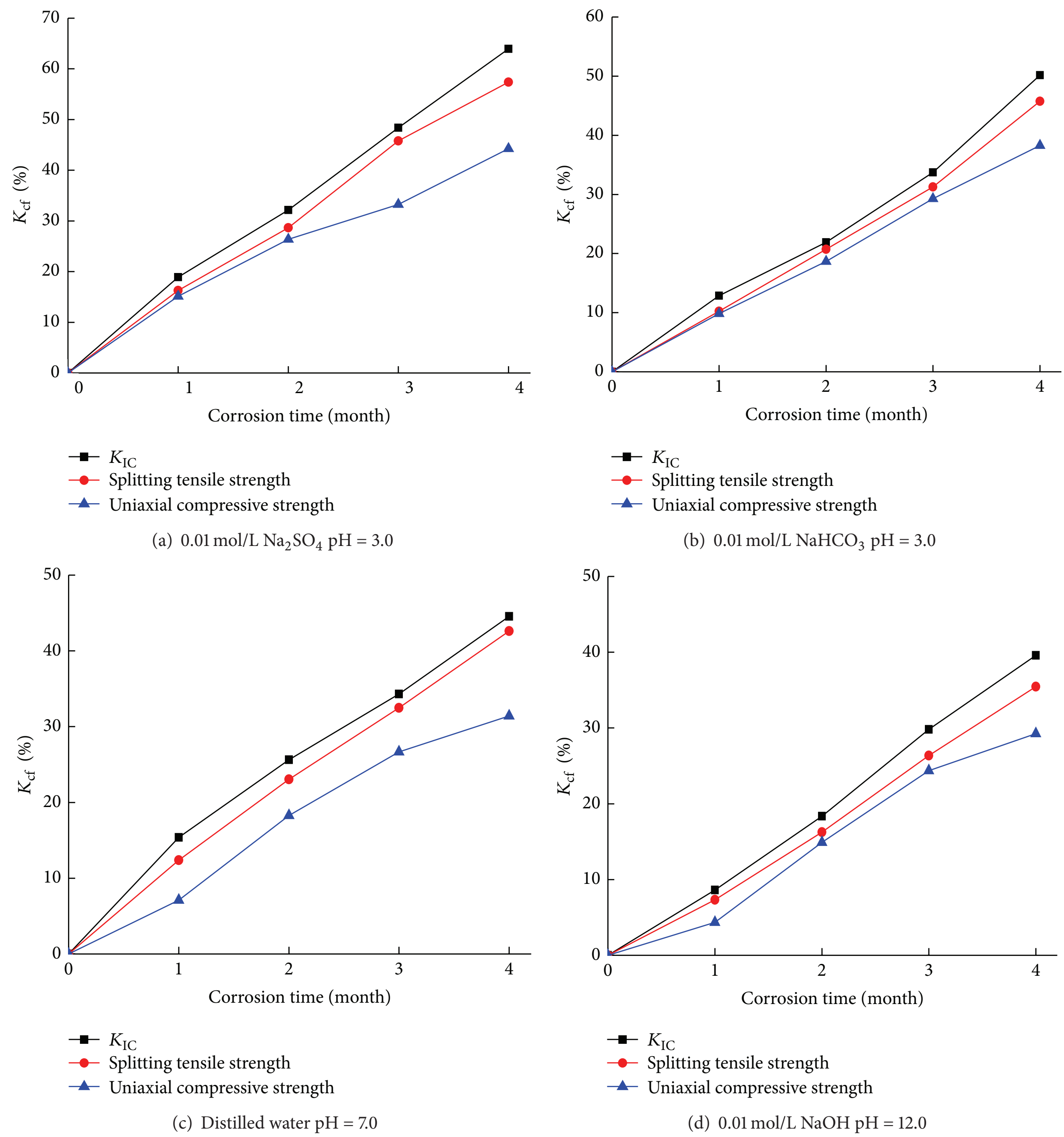
As shown in Figure 9, after the effect of chemical corrosion, the crack propagation radius of the granite specimens generally showed a gradually decreasing trend, indirectly indicating that the strength characteristics of the granite specimens had an increasing deterioration tendency. The results were consistent with the analysis of the deterioration regularity in the splitting tensile strength and the compressive strength of the granite specimens. Equation (5) indicates that the deterioration degree of the specimen fracture toughness is significantly higher than that of the splitting tensile strength when the splitting tensile strength and crack propagation radius of the granite specimens simultaneously decrease. This condition serves as a good explanation for the test phenomenon in Figure 8; that is, the deterioration degree of the specimen fracture toughness is the highest, followed by those of the splitting tensile strength and compressive strength the lowest.

4. Analysis of the Damage Variable Mechanism under Chemical Corrosion

4.1. Damage Variable. Based on the preceding analysis on the damage deterioration degree of granite specimens under the effect of chemical solutions, the damage variable D can be expressed according to the changes in porosity given by

$$D = \frac{n_N - n_0}{1 - n_0}, \quad (6)$$

where n_0 denotes the porosity of the granite specimens at the initial state, and n_N refers to the porosity of the granite



(a) 0.01 mol/L Na_2SO_4 pH = 3.0

(b) 0.01 mol/L $NaHCO_3$ pH = 3.0

(c) Distilled water pH = 7.0

(d) 0.01 mol/L NaOH pH = 12.0

FIGURE 8: Relationship between the deterioration rate of the mechanical characteristics of granite specimens and corrosion time under different water chemical solutions.

specimens under the effect of chemical corrosion after N months of chemical corrosion.

The damage variable of the granite specimens under the effects of different chemical solutions for different chemical corrosion times was evaluated based on (6). The results are shown in Figure 9. As shown in the diagram, as the chemical corrosion time increased, the damage variable of the granite specimens under different conditions gradually increased. A certain distinction existed in the variation regularity in the damage variable when the specimens were immersed in different chemical solutions.

The damage variable of the granite specimens was higher in the 0.01 mol/L Na_2SO_4 (pH = 3.0) solution than in the alkaline 0.01 mol/L NaOH (pH = 12.0) solution or in the pH = 7.0 distilled water. The damage variable of the specimens in the alkaline 0.01 mol/L NaOH (pH = 12.0) solution was the lowest; that is, $D_{Na_2SO_4} > D_{\text{Distilled water}} > D_{NaOH}$. Thus, the 0.01 mol/L Na_2SO_4 (pH = 3.0) solution aggravates the chemical damage deterioration of the granite. By contrast, the NaOH solution had a certain inhibiting effect on the chemical damage deterioration of the granite specimens.

When the solution concentration and pH value remained unchanged, the chemical damage deterioration degrees of the tensile strength and compressive strength of the granite specimens were higher in the 0.01 mol/L Na_2SO_4 (pH = 3.0) solution than in the 0.01 mol/L $NaHCO_3$ (pH = 3.0) solution.

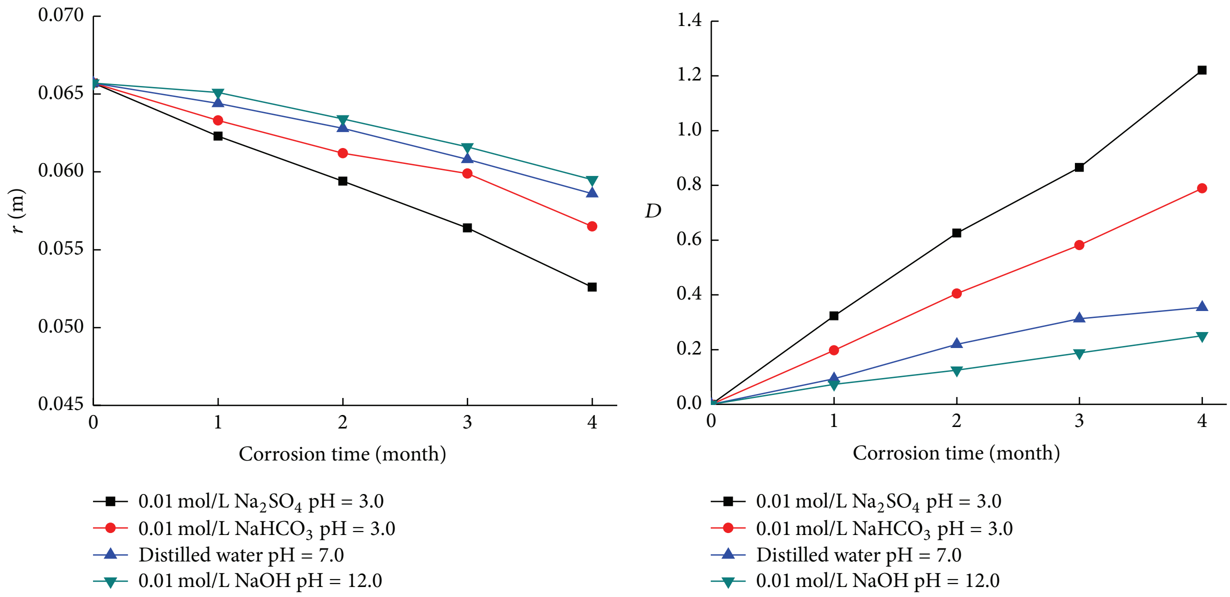


FIGURE 9: Relationships between crack propagation radii, damage variable of granite specimens, and corrosion time under different water chemical solutions.

Therefore, SO_4^{2-} ions aggravated the chemical deterioration degrees of the tensile strength and compressive strength of the granite specimens.

4.2. Effect of Chemical Corrosion Damage on the Mechanical Parameters of the Granite Specimens. The damage variable for the granite specimens that underwent different chemical corrosion times in various chemical conditions was calculated based on (6). Figure 10 shows the relationship between the damage variable and physical mechanical parameters, including P-wave velocity, fracture toughness K_{IC}, splitting tensile strength, and compressive strength of the granite specimens.

As shown in Figure 10, the P-wave velocity, fracture toughness K_{IC}, splitting tensile strength, and compressive strength of the granite specimens affected by chemical solutions gradually deteriorated as the damage of the specimens became increasingly severe. Consequently, chemical corrosion led to the gradual deterioration of the specimens. Moreover, as the chemical corrosion time increased, the damage deterioration of specimens also increased. The accumulated damage might result in the deterioration of the physical and mechanical parameters of the granite to varying extent.

Linear regression was conducted for Figure 10. The respective relationships between the mechanical parameters and the damage variable of the granite specimens were obtained as follows:

$$K_{IC} = 6.2546e^{-0.7815D}, \quad R^2 = 0.9478, \tag{7}$$

$$\sigma_t = 9.509e^{-0.6728D}, \quad R^2 = 0.9260, \tag{8}$$

$$\sigma = 120.26e^{-0.4834D}, \quad R^2 = 0.9723, \tag{9}$$

$$v_p = -238.58D + 4001.2, \quad R^2 = 0.9478. \tag{10}$$

5. The Engineering Properties of Marble after Chemical Solutions

The engineering properties of a rock mass are described by the relevant quantitative physical and mechanical properties. Accordingly, this test data was validated by calculating two parameters, the saturated uniaxial compressive strength (R_c), and the weathering reduction factor of strength, respectively.

The degree of rock hardness is determined by the saturated uniaxial compressive strength of the rock. The hardness degree of our granite specimens immersed in the chemical solutions was divided based on the standard specified in the Standard for Engineering Classification of Rock Masses (2014), GB/T 50218-2014. The results show that the hardness degree of granite specimens subjected to various degrees of deterioration after chemical solution was less than that of natural sandstone.

The weathering reduction factor of strength is equal to the strength of granite after chemical corrosion, divided by its initial natural strength. Statistical analysis of test results showed that the weathering degree of natural granite was weak weathering, but that of the granite specimens was aggravated after the chemical corrosion. With the chemical etching time increased, the weathering degree of granite gradually increased. Nevertheless, the weathering degree of the specimens differed when they were immersed in different chemical solutions, causing differing weathering

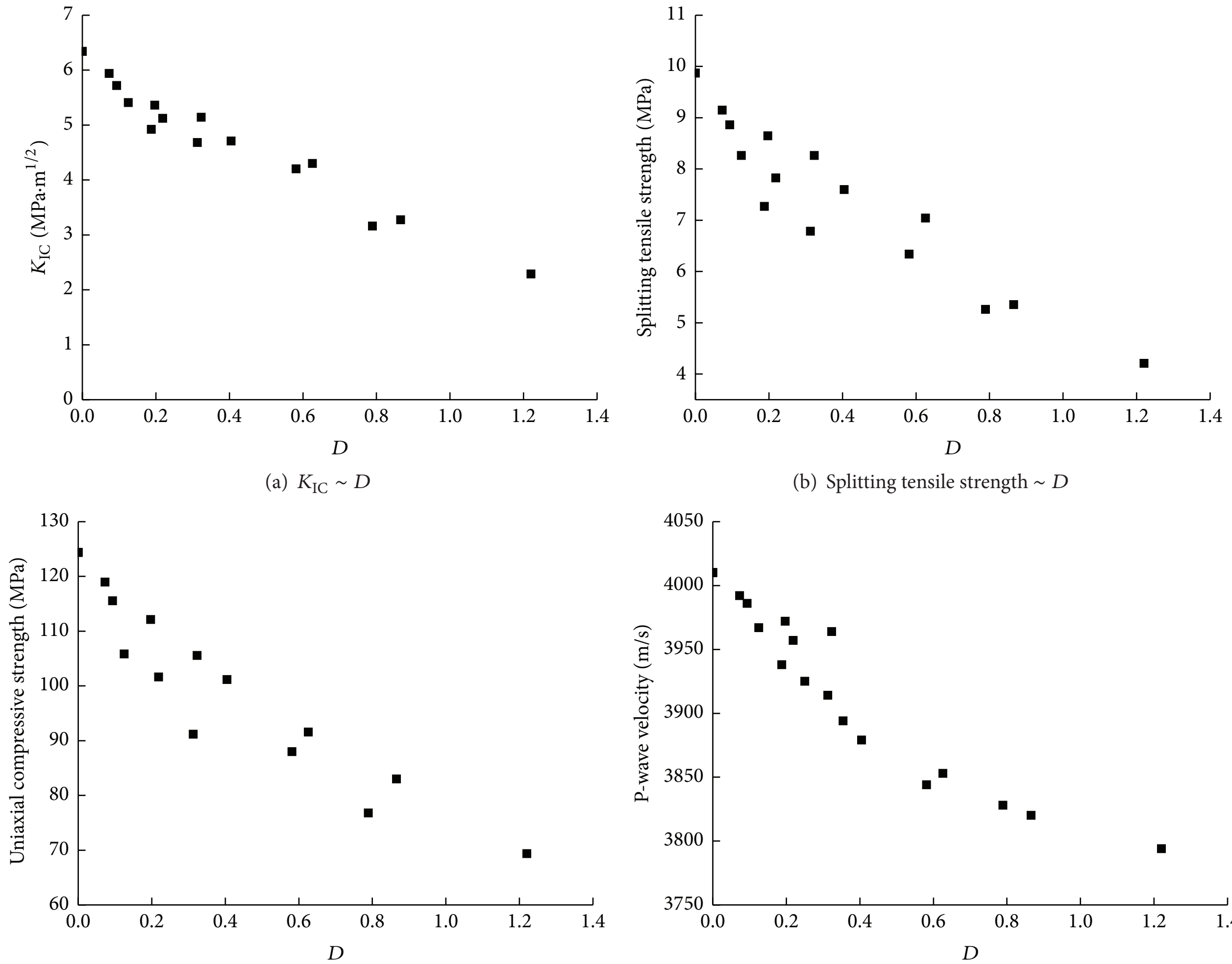


FIGURE 10: Relationship between physical and mechanical parameters and damage variable of marble specimens.

degrees with corrosion time. The greater the influence of chemical solutions on the deterioration degree of granite, the earlier the chemical etching time happened. The weathering degree of granite specimens converted from weak weathering to moderate weathering in different chemical solutions. Because the deterioration degree of granite was greater in the 0.01 mol/L Na_2SO_4 (pH = 3.0) and 0.01 mol/L $NaHCO_3$ (pH = 3.0) solutions than that in the 0.01 mol/L NaOH (pH = 12.0) and distilled water, strong weathering of granite in 0.01 mol/L Na_2SO_4 (pH = 3.0) and 0.01 mol/L $NaHCO_3$ (pH = 3.0) solutions happened one month earlier than that in 0.01 mol/L NaOH (pH = 12.0) solution and two months than in distilled water.

6. Conclusions

(1) Granite specimens under the effects of different chemical solutions showed an overall remarkably weakening trend. The splitting tensile strength, compressive strength, and K_{IC} of the specimens displayed a roughly identical deteriorating trend as the chemical corrosion time increased. However, variations in the deterioration degrees of the mechanical parameters were observed. The deterioration degree of fracture toughness was the highest, followed by those of splitting tensile strength and compressive strength is the lowest.

(2) Different effects of various chemical solutions on the chemical damage deterioration degree of the granite specimens were observed. The 0.01 mol/L Na_2SO_4 (pH = 3.0) solution aggravated the chemical damage deterioration of the granite specimens. By contrast, the 0.01 mol/L NaOH (pH = 12.0) solution had a certain inhibiting effect on the granite specimens. Moreover, the 0.01 mol/L Na_2SO_4 (pH = 3.0) solution had a greater effect on the chemical damage deterioration degree of the granite specimens than the 0.01 mol/L $NaHCO_3$ (pH = 3.0) solution. Hence, SO_4^{2-} ions could aggravate the damage deterioration of the granite specimens.

(3) A good linear relationship existed between the fracture toughness K_{IC}, splitting tensile strength, and compressive strength of the granite specimens that underwent chemical corrosion. After being affected by chemical solutions, the crack propagation radius of the granite specimens generally

showed a gradually decreasing trend. Such a result indirectly indicated that the strength characteristics of the granite specimens had a gradually deteriorating trend.

(4) The damage variable was established based on the changes in the porosities of the granite specimens. The damage variable gradually increased as the chemical corrosion time increased. As the damage of the specimens became increasingly severe, the K_{IC}, splitting tensile strength, compressive strength, and P-wave velocity of the granite specimens affected by the chemical solutions also gradually deteriorated. The relationships between the fracture toughness K_{IC}, splitting tensile strength, compressive strength of the specimens, and damage variable showed an exponential function, whereas the relations between the P-wave velocity of the granite specimens and the damage variable were linear.

Competing Interests

The authors declare that they have no competing interests.

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