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Influence of temperature and roughness of surrounding rocks on mechanical behavior of rock bolts

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ABSTRACT

In order to solve the degradation problem of rock bolts and the safety of a support structure for a high geothermal tunnel in a dry heat environment, various tensile tests of rock bolts were conducted at different temperatures and different levels of roughness of the surrounding rocks in this paper. The roughness of the surrounding rocks was simulated through different types of steel tubes, and dry heat environment was simulated through different temperatures of a drying oven. Based on the first interface (bolt to grout interface) and the second interface (grout to pipe interface) pullout tests, the load-displacement curves of rock bolts were obtained at different temperatures and roughness. The results showed that temperature had little effects on the failure mode, but roughness of the surrounding rock had a great influence on the pullout strength. With an increase in roughness, the tensile strength increased, and the bolting effect was enhanced. For the non-threaded specimens, the interface bond strength of the first interface was larger than that of the second interface, and the second interface showed a kind of shear failure. Finally, it was revealed that the dependence of ultimate tensile force on temperature and roughness of surrounding rocks obeyed a cubic and quadratic polynomial function, respectively.

1. Introduction

The use of geotechnical rock bolts is a kind of effective support measure by the means of the interlock formed in the structure [1]. Such a bolting support has become a main method in a tunnel and in slope engineering [2]. With the construction of bigger, deeper and longer tunnels in China, the problem of high geothermal damage will seriously affect the performance of the bolting support in tunnel engineering [3–5].

Since the inception of the rock bolt structure, scholars at home and abroad have conducted many experiments and theoretical studies on the performance and influence of the pullout behavior of the rock bolt, and have achieved some valuable research results. Zhang et al. [6] studied the mechanical properties of grouted rock under freeze-thaw cycles through the indoor model test. Delhomme et al. [7–10] carried out much theoretical analysis and conducted an experimental study of the mechanics and rock bolting mechanisms. Zhi et al. [11]carried out field tests on the failure mechanism and adhesion characteristics of rock bolts for different surrounding rock masses by means of full rock bolt-length bonded adhesive strain gauges. Xue et al. [12] systematically studied and analyzed the interfacial bond strength between rock bolts of CFRP reinforcement and different bonding materials by a tensile test on 48 specimens of rock bolts.

Indraratna et al. [13] studied the factors affecting the yield and deformation of the surrounding rock using the mechanical model by which rock mass was reinforced by rock bolts. Ferrero [14] pointed out that the main factors affecting the shear strength of rock bolts are the rock bolts' materials, the size of the rod body and the type of rock mass, using the shear test of rock bolts. Through the jointed rock mass shear test on the pre-stressed rock bolts, Zhang Wei et al. [15,16] studied the mechanism and mode of shear properties on the rock bolt to the rock joint.

Although researchers have conducted various studies on the pullout performance of rock bolts, the investigations on the influence of temperature and roughness of surrounding rock on pullout strength is very rare in the literature. However, engineering practice shows that the temperature of the rock bolts and the roughness of the surrounding rock play a very important role in the bolt performance [1]. Therefore, for both theoretical significance and engineering applications, it is necessary to establish a relationship between mechanical behavior and temperature and roughness of the surrounding rocks. In the present work, based on the tensile tests of rock bolts with different

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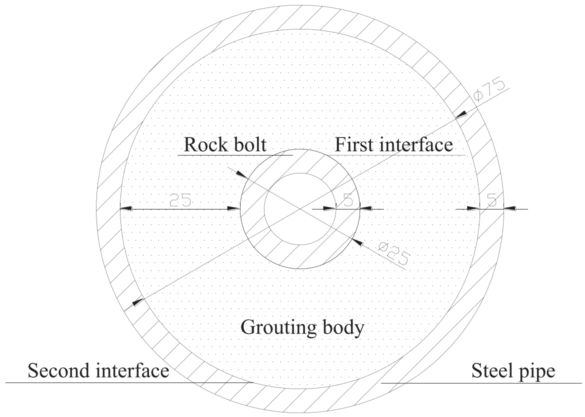

Fig. 1. Section of rock bolts (unit: mm).

temperatures and roughness, we systematically investigate and analyze their load-displacement curves, ultimate tensile forces, and failure modes. Such a investigation can provide fundamental data and a theoretical basis for mechanical performance of rock bolts in a complex engineering environment. Here it is note that namely, the temperature of the rock bolts can affect the bolt performance, but the temperature of the rock bolts depends strongly on the temperature of the surrounding rocks, and even both are the same if time is long enough. As a result, in nature, the effect of the temperature of the rock bolts results from that of surrounding enthronements such as rocks.

2. Test conditions

2.1. Specimen design

The rock bolt specimens designed for the test consist of four parts: a steel pipe with an inner diameter of 75 mm and length of 100 mm. rock bolt with length 300 mm, a waterproof cushion and grouting material between the steel pipe and the rock bolt. For the pipes of 100 mm length it is mainly considered that the interfacial force of the grouting material between the rock bolt bar and the steel pipe is more uniform during the tensile test. The contact surface between the rock bolt bar and the grouting material is called the first interface, and the contact surface between the pipe and grouting material called the second interface, as shown in Fig. 1. In order to study the influence of the rock bolts' environment temperature on stress on the different interfaces, this tensile test will be on the first and second interface of the rock bolt specimens. In the tensile tests on the first interface, the grouting materials and steel pipes as a whole structure are loaded by forces. The rock bolts can transfer the load only through the first interface. In the first interface pullout tests, the non-threaded steel pipe specimens are taken as a typical example. In the second interfacial tensile test, the grouting material and the steel pipe are loaded respectively; the two interfaces will transfer the load. In this test, a steel pipe simulates the surrounding rock, and the roughness of the internal wall of the steel pipe is treated in different degrees. Pipes were cut and their roughness constructed in the Southwest Jiao tong University Industrial Centre by machine tools, so that there are three types of molding steel pipes: double-threaded in the inner surface; an inner surface with a single thread; the ordinary type with no thread in inner surface, as shown in Fig. 2.

The grouting materials with water-cement ratio 0.45 and cement-sand ratio 1.0 were grouted, poured and rock bolted to the mold, as presented in Fig. 3. The rock bolt specimens were placed in a constant temperature environment of 20 ℃, 35 ℃, 50 ℃, 70 ℃ with ages of 7 days and 28 days (GB50086-2001). The following rules were applied to the specimens: W1-20-7 refers to the non-threaded steel pipe - first interface - temperature of 20 ℃- age of 7 days; D represented the steel pipe with a single thread and S represented the double-threaded steel pipe.

2.2. Simulations and tests of roughness of the surrounding rocks

The roughness of the steel pipes was measured according to the national standard such as the filling-sand method (For details, please refer to [17]). Here it is also noted that the measured data are the average value of the three tests. The average depth of filling sand represented the roughness: average depth of filling sand equals volume of standard sand divided by surface area in steel pipe wall. It was determined that the average depth of the sand filling the steel pipe with a single thread was 0.0542 mm, and the average depth of the sand filling the steel pipe with double threads was 0.1175 mm. The roughness of the non-threaded pipe is assumed to be 1.0×10^{-5}. In order to research qualitatively the influence of roughness on the rock bolts' pullout strength, this paper took the relative roughness to be 0.01, so that steel pipe with single-threaded roughness is 5.42, double-threaded roughness is 11.75 and non-threaded roughness is 0.001.

2.3. Testing equipment

The test to assess the pullout strength and displacement deformation of the rock bolts was carried out in the laboratory of building materials of Southwest Jiao Tong University. The test of pullout strength was carried out on the 100 t hydraulic universal testing machine. See Fig. 4. The slip displacement between the rock bolt bar and the grouting material, and the

(a) single-threaded steel pipe (b) double-threaded steel pipe (c) non-threaded steel pipe

Fig. 2. Internal wall roughness of steel pipe.