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Effect of different factors on propagation of carbon fiber composite cement grout in a fracture with flowing water

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HIGHLIGHTS

- The most significant influence factor of plastic viscosity is cement water ratio.
- Grout propagation length decreases with the increase of plastic viscosity.
- Grout propagation length increases with flow velocity, grouting pressure and time.
- The most significant influence factor of grout propagation length is grouting time.
- Joint roughness coefficient has insignificant effect on grout propagation length.

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ABSTRACT

Although grouting has been widely used in fractured rock mass, grouting in fractured rock mass with flowing water environment is still a big challenge. In order to get a great grouting effect for the case with flowing water, carbon fiber was added to the cement grout and a new grout for flowing water environment was provided, and a series of grouting test in the fracture with flowing water was conducted. Effects of plastic viscosity, flowing water velocity, grouting pressure and roughness coefficient of joint on the propagation of carbon fiber composite cement grout was analyzed. The test results showed that propagation length of carbon fiber composite cement grout increases with the increase of flowing water velocity, grouting pressure, roughness coefficient of joint and grouting time, and it decreases with the increase of plastic viscosity of carbon fiber composite cement grout. Grouting time has the greatest impact among the five factors. Finally, a fitting equation based on the test results was deduced.

1. Introduction

Grouting technique has been widely used in all kinds of industries since its first introduction by Charles Beriguy in 1802. The grouting technique is primarily applied to the improvement of surrounding rock and gushing water plugging in underground engineering [1]. Though the fracture grouting theory in flowing water environment has achieved some preliminary accomplishments, it still lags behind the engineering practice. The main cause is the grout diffusion in fractured rock mass depends on many factors, such as properties of grout material and fractured rock, the diffusion rule of the grout in fracture and the interaction between grouts and rock fracture.

Many scholars have conducted the research of grout diffusion, and achieved a series of results. Funehag deduced the propagation length formula of Newton fluid based on experimental results with the consideration of time-varying grout viscosity [2]. Jeongyun prepared PAE cement mortar, and determined the flow property and crack resistance properties [3]. Zhang assumed that the rock mass is a composition of rock particles and random cracks [4]. The cracks were grouted in whole or in part with cement slurry. Based on micro damage mechanics, the micro failure criterion of grouted rock mass was established. Luo deduced the flowing equation of Bingham grouts in smooth and inclined cracks based on the Navier Stokes equation of plane between the plates [5]. The model showed that the flow velocity of grout reduced with time. Kelessidis studied the diffusion law of H-B fluid in pipe and the regression analysis was carried out on three rheological parameters of the model [6]. Fransson proposed to use the pressure change of the integral area to calculate the distribution of grouting pressure, and verified by short-term pressure grouting test and constant pressure grouting test [7]. Xing used a kind of improved polymer

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grouting material in the repair of the shear zones in Chinese Jinping hydropower station [8]. The grouting enhanced the completeness of the fracture's structure and greatly reduced the coefficient of permeability. Khayat introduced a the repairing method of grouting in concrete bridge piers damaged under water including surface treatment, crack sealing and injection and quality control regulations [9]. The research results mentioned above greatly promotes the development of grouting theory and solves a series of problems in engineering. However, it is not completely applicable to fractured rock mass with flowing water. The main reason is that the grouting theories mentioned in the previous content is based on groundwater seepage mechanics theory, which is more suitable for the homogeneous porous medium [10].

The research for grouting theory of fractured rock mass is relatively few [11]. An Austrian scholar simulated flow process of grout in a single fracture [12]. Tests on diffusion of grout were carried out in three different kinds of concrete block models, which are split form fractures inside concrete blocks, fractures consist of different concrete blocks. It shows the relationship between diffusion and fracture spacing, fracture flow, grouting pressure, slurry viscosity, roughness, other physical quantities. Houlsby carried out a single fracture grouting simulation test, in which the slurry pressure, velocity and other parameters of grouting were detected [13]. He finally obtained the relationship between the measured slurry pressure, flow and other parameters of grouting. Terashiand some other people conducted experimental research on the diffusion of grout [14]. Gothall and some others conducted model test on the effect of the slurry on fracture deformation and fracturing, the fracture aperture changes formula was obtained [15,16]. Yang did the research on the diffusion of non-Newtonian slurry in fracture generated randomly based on permeation grouting control theory in the fractured rock mass [17]. Li and some others conducted flowing water model test on grouting in fractured rock mass [10,18,19]. They proposed the U shaped grout diffusion law and cement slurry's partition diffusion mechanism.

The researches mentioned above mainly focused on smooth fractures and general cement grouts. The surface roughness of fractured rock mass and the flowing water has a great impact on the diffusion of grouting. Therefore, the research about the effect of joint roughness coefficient and flowing water on grout diffusion is very necessary. In this paper, Carbon fiber was added to the cement grout and a new kind of grout for flowing water environment was provided. Grouting model tests with different joint roughness coefficient and flowing water environment were conducted, and influence factors on propagation of carbon fiber composite cement grout in the model were analyzed.

2. Experimental investigation

2.1. Experimental setup

The propagation length of grouts is very important for the grouting design and process control of grouting. In order to study the relationship between plastic viscosity of grout, pressure of grouting, velocity of flowing water, joint roughness coefficient, time and the propagation length, a low-pressure grouting simulation test device was designed. The device can meet the requirements of simulation of fracture, grouting process recording and data acquisition. This device consists of a water injection equipment, grouting equipment, photographic equipment and crack simulation platform (see Fig. 1).

2.1.1. Water injection setup

Injection setup includes the pump (flow at 1.5 m^3/h), water storage setup, power supply, water pipe, valves and pressure gauge.

2.1.2. Grouting setup

The grouting device is composed of a rack, a pulley, a rope, a grout storage barrel (diameter at 40 cm, height at 50 cm), a steel pipe, three-way valve, valves, diaphragm pressure gauge and fixing devices. Height of the iron shelf is 5.5 m with a fixed pulley with a rope around it. One end of the rope is connected to grout storage barrel, and the other is fixed on the bottom of the shelf. At the bottom of the grout storage barrel there is a copper interface of 15 mm inner diameter, which is connected to a three-way valve on the ground. Pipe is connected with a diaphragm pressure gauge in order to measure grout pressure. The other end of the pipe is connected to the fracture model through a 0.5-meter-long outlet, using a valve to control grouting.

2.1.3. Data acquisition setup

Data acquisition setup uses the video equation of the camera. The camera is fixed at a certain height from the simulated crack, so that it can shoot panoramic view of the whole simulated crack. The diffusion process of grout will be recorded in the video.

2.1.4. Fracture model

Each simulation of crack device is composed of two blocks of sawtooth shape concrete plate, steel bar (20 mm in length, 8 mm in diameter), soft glass, glass glue, steel tape and transparent tape. On the middle axis of the upper concrete plate lies one water inlet hole, one injection hole and one steel bar between two pieces of concrete. Copper thread interfaces with 15 mm diameter are embedded in the water inlet hole and grouting holes. The distance of water inlet hole and grouting holes in fracture's length direction is 100 mm and 700 mm, respectively. The length of the fracture is 1500 mm, width 200 mm, fracture aperture is 20 mm, as shown in Fig. 2. In order to obtain different roughness, four different fracture models were made.

Based on the research of Deng [20], the value of joint roughness coefficient (Table 1) can be obtained through the Eq. (1) below.

$$JRC = 0.81 \times (-3.78 + 74.33Z + 5.06R)^{1.08D} \quad (1)$$

where: Z— slope expectation; R— elongation; D— fractal dimension.

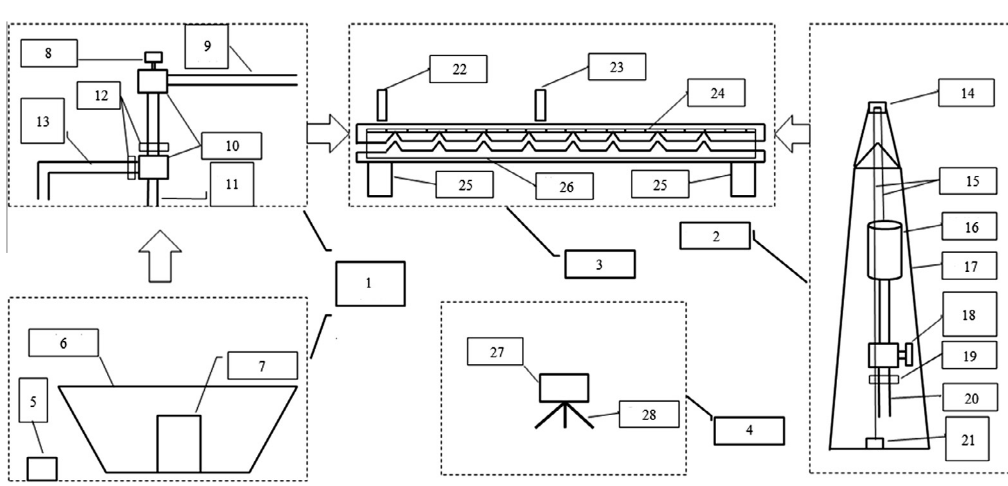

Fig. 1. Schematic diagram of experimental apparatus.