

Testing Rig for Fracture Grouting

By ZHOU XINGWANG¹ and LIU SHUQING¹

Beijing Research Institute of Mine Construction,
Central Coal Mining Research Institute, Hepingli, Beijing
China

ABSTRACT

The paper introduces a newly developed multi-function test rig for fracture grouting. This test rig has many functions and its performance is consistent. It can control and adjust accurately the opening degree of fissures and static pressure; it can measure automatically the quantity of grout injected; it can measure precisely pressure drop of grout in fissures; it can test the results of injection, including effective dispersed distance, anti-filtration capacity of consolidated body, mechanical strength, etc. It can inject a single or two grouts into one or several fissures at a pressure of 16 MPa. Therefore, it is an ideal test rig for fracture injection.

The paper depicts all the components of the test rig, its performance and application of the results obtained from fracture grouting tests. Examples are briefly described.

I. INTRODUCTION

Fracture grouting, as a technique for sealing off water and reinforcing water-bearing strata and water-proof structure, has found wide-spread application in the world. In order to conduct further investigation on fracture grouting, the grouting researchers both at home and abroad show great interest to laboratory test of fracture grouting. Laboratory study plays a very important role in promoting development of grouting techniques.

To meet the actual needs for undertaking fracture grouting tests in the lab we have developed a multi-function test rig. Under the guidance of Mr. Shen Jiliang, mine construction expert, and Mr. Liu Xingpu, Senior Engineer, satisfactory results have been obtained by using this test rig to study problems, such as grouting pressure and results of fracture

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grouting.

II. MULTI-FUNCTION TEST RIG FOR FRACTURE GROUTING

The multi-function test rig we developed consists of grout pumping system, grouting platform, and system for controlling static pressure, as shown in Fig.1.

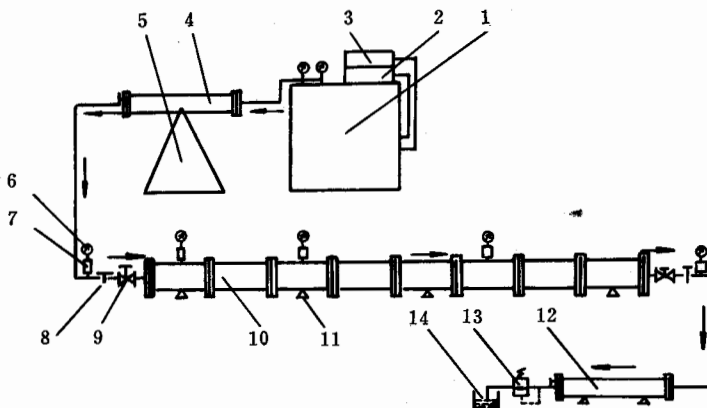


Fig.1 Sketch of test rig for fracture grouting
 1 - metering pump; 2 - speed regulator;
 3 - counter; 4 - storage tank; 5 - support;
 6 - pressure gauge; 7 - buffer; 8 -exhaust;
 9 - stop valve; 10 - fracture grouting model;
 11 - wooden base; 12 - grout isolating tank;
 13 - overflow valve; 14 - grout collecting cup.

1. Grouting pumping system

Grout pumping system consists of a pump, a storage tank, a support, and grout pipelines. The grout support system, using pump to convey water, using water to move the grout, is adopted. This has fundamentally solved many problems in connection with pumping suspension type of grouts, like cement grout, directly with pump, such as, wear of mechanical parts, like cylinder, piston, etc., and labor-intensive work, like dismantlement and cleaning of pump after grouting.

The pump can automatically control and precisely measure its delivery and pressure of grout. A special piston is installed in storage tank, which isolates the pressurized water conveyed by the pump with grout, and transmits water pressure for moving the grout. The support enables storage tank to rotate at any angle, so as to prevent the particles of suspension type grout from precipitating.

2. Grouting platform

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Grouting platform is the core of the test rig. It is composed of several sections of moulds for fracture grouting. The grouting moulds fall into two categories, namely, ordinary moulds and pressure measuring moulds. The pressure-measuring moulds are of special structures. They can measure the grout pressure at a certain position in the fissure, and the pressure drop of grout along the route in the direction of grout dispersion. Each mould is 0.5 m long. Valves and pressure measuring elements are fitted on both ends of the platform.

How to mock fissures in the laboratory is a key problem, which should be solved first for fracture grouting. In the past, plate moulds made of steel plates or plexiglass plates were used both at home and abroad. This type of fissure mould can stand low grouting pressure; and it is difficult to control accurately the opening degree; and it can not measure the anti-filtration capacity and mechanical strength of the consolidated body; the fissure plane formed by steel or plexiglass plates differs, to a great extent, from fissure planes in rock strata. We have designed a tubular type of mould for fracture grouting based on site grouting conditions. According to the purpose of the test, fractures of different openings with a horizontal width of 93 mm in the tubular mould, and the fracture plane is a flat and smooth plane of cement mortar. The fracture plane formed in this mould is close to actual fracture plane in the rock strata and can stand a pressure of 16 MPa, and can ensure the opening of fracture remain unchanged. The platform is of modular structure, the opening and length of fractures and number of fractures can be selected to suit the need of test.

3. System for controlling static pressure

To simulate the static pressure in the grouting site, a control system has been designed in the test rig. This system consists of an over-flow valve, a grout isolating tank and pipelines. The over-flow valve is used to control the static pressure. The grout isolating tank is employed to protect the over-flow valve from being damaged by grout that passes directly through the valve.

4. Methods for checking results of grouting

The following methods can be used to examine the results of grouting after each time of grouting and after a period of curing time.

1) Anti-filtration test and measurement of effective dispersed distance

The pump is connected with the grouting platform in series by a pipe line, thus a system is formed for making filtration test. Pressurized water is pumped to the platform for testing anti-filtration capacity of the consolidated body (we call it platform filtration test). The pump is connected with each section of mould in the same way, the filtration

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resistant capacity of set grout in the mould can be measured (we call it section filtration test). The effective dispersed distance of grout, i.e. the maximum distance, when anti-filtration capacity is greater than 0 MPa, can be obtained after section filtration test is completed.

2) Examination of filled fissures and mechanical performance test of the grout

After filtration test, the set grout and its surrounding mortar in each section of mould are cored by diamond drill. Samples of consolidated grout are taken from specified position of core, 50 x 50 x 50 mm in size, for strength test. The shear strength of the set grout is obtained when samples are tested in a press.

III. TEST RESULTS AND ANALYSIS

A series of tests have been made with above-mentioned test rig. The paper describes results of five tests only. The test conditions are shown in Table 1. The results are shown in Table 2 to 5 and Fig.2 where P represents grouting pressure, and t, grouting time. From Table 2 we can see that the greater the opening of the fissure and the more dilute the grout, the more quantity of grout is injected.

From Fig.2 we can see that the grouting pressure versus time curve of each time of grouting can be divided into four types, namely, flat-gentle type, in test 1; rapid rising type, in test 2; flat-rising type, in test 3 and flat-rising-falling-flat-rising type, in test 4 and 5. Based on Fig.2 and Tables 3-5, we can draw the following conclusions:

1. The grouting results indicated by the former two types of p-t curves are not good. However, results shown by latter two types of p-t curves are ideal. When flat-gentle type of curve appears, the gel time of grout should be shortened in time, or thick grout should be injected in steps so as to avoid waste, and to improve the results gradually.
2. The anti-filtration capacity and mechanical strength of consolidated grout do not always decrease in the direction of grout dispersion.

VI. APPLICATION OF TEST RESULTS

The above test data play a guiding role in improvement of grouting results.

High pressure grouting was applied from within an incline face of a colliery into a layer of limestone with well-developed fissures, and a grout pad was left in mudstone. The grouting section was 65 m long. Six grout holes were drilled. The p-t curves of 3# hole are shown in Fig.3. Curve(a) is similar to Curve 1 in Fig.2. Repeated grouting was carried out according to the features of flat-gentle

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Table 1 Test conditions

No. of test	Opening of fissures mm	W/C ratio of grout	Static pressure MPa	Delivery of grout ml/min	Length of platform m
1	2.0	0.8:1	2.0	22	4
2	0.5	0.8:1	2.0	22	4
3	0.5	1:1	4.0	22	4
4	1.0	0.8:1	4.0	22	4
5	1.0	1:1	2.0	22	4

Table 2 Final grouting pressure and quantity of grout injected

No. of test	1	2	3	4	5
Final grouting pressure MPa	3.8	16	16	16	16
Quantity of grout injected, ml	3454	286	1166	1760	2816

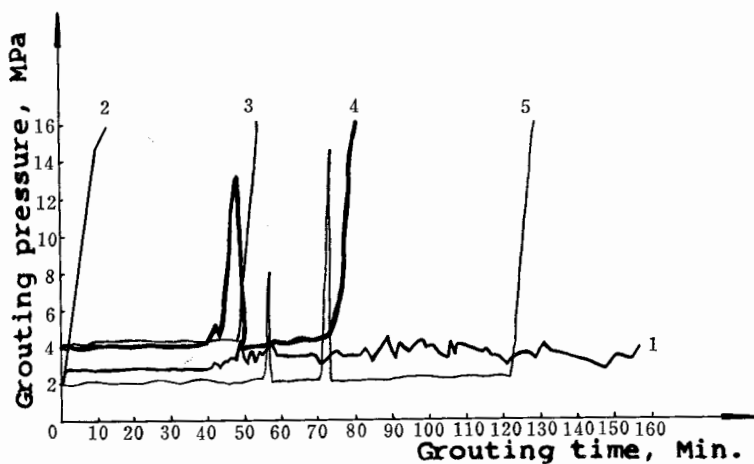


Fig. 2 Grouting pressure vs time curve

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Table 3 Results of filtration test and condition of filled fissures

No. of test	Platform anti-filtration capacity, Mpa	Section anti-filtration capacity, MPa. Condition of filled fissures							
		No. of mould							
		1	2	3	4	5	6	7	8
1	0.25	0.1	0.1	0.05	0.1	0.1	0.1	0	0
		✓	✓	✓	✓	✓	✓	✓	✓
2	12.4	10.6	0.1	0	0	0	0	0	0
		✓	✓	✓	✓	x	x	x	x
3	> 13	2	6.3	9.4	0.35	0	0	0	0
		✓	✓	✓	✓	✓	✓	✓	✓
4	> 14.2	4.8	0.6	3.65	4.9	6.3	3.7	0	0
		✓	✓	✓	✓	✓	✓	✓	✓
5	> 16	4.5	7	0.7	0.3	0.1	6	1	9
		✓	✓	✓	✓	✓	✓	✓	✓

✓- fissures fully filled; ✓- fissures basically filled;
 ✓- fissures partially filled; x - fissures without grout.

Table 4 Effective dispersed distance

No. of test	1	2	3	4	5
Effective dispersed distance, m	3	1	2	3	> 4

Table 5 Shear strength of consolidated grout

No. of test	Age d	Shear strength, Mpa			
		No. of mould			
		1	3	4	5
2	15	2.88	-	-	-
4	32	14.37	9.66	14.23	18.69

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based on analysis of the above-mentioned data. And after 4 times of grouting, the designed final pressure and quantity of grout were reached. In the 4th run of grouting, technological adjustment method was introduced by changing concentration of grout. As a result, all fissures and cracks with different openings were filled. The final pressure of all six grout holes was 12 MPa. Single grout or cement grout was injected in the whole project. The water-cement ratio greater than 0.8:1 amounted to 78.34%. In total, 165 tons of cement was used. Based on prediction of Table 3, a reliable water-sealing curtain was formed around the roadway after grouting. When driving roadway in grouted section the water inflow reduced from 219.56 cu m/h to 1 cu m/h. It was proved that the above results were reliable, which could give guidance to grouting in sites, and would help to assess the results.

Surface pre-grouting was employed in a colliery in Shandong province, where such water-bearing rock strata occurred at a depth of 150 m to 470 m, as sand layers with gravel, sandstone, siltstone, and limestone. Six grout holes were arranged, which were divided into two groups for grouting. The length of a grout hole was divided into 14 sections of 20-30 m.

Depending upon the quantity of water absorbed by the hole in pressure test and upon p-t curve, the following methods were adopted.

1. Intermittent grouting, i.e. after injecting 2-3 cu m of grout, grouting stopped for about 10 minutes and then started again. The grouting run finished when this repeated for 3-4 hours.
2. Stepwise repeated grouting, i.e. the standard for each small section of grouting was achieved by several runs of grouting.
3. Technological adjustment method, i.e. the concentration of grout was changed with changes of pressure and quantity of grout absorbed by rock strata.

In addition, measures were taken to enhance the final pressure of grouting and quantity of grout injected, to overcome the effect of deviation on quality of grouting, to improve the grouting results. They were: moving the position of hole, hole sealing and lowering of a mechanical pipe into the hole for deviation correction. The water-make in shaft after grouting reduced from 400-112.08 cu m/h to 0.3-3.8 cu m/h.

V. CONCLUSIONS

1. The test rig described has multiple functions, and can be used for obtaining good results in many aspects.

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Therefore, it is an ideal laboratory test facility.

2. The pressure-time curves can be divided into 4 types. For one run of grouting, the flat type and rapid-rising type of curves correspond to bad grouting results, and flat-rising type and flat-rising and falling-flat-rising type of curves represent good grouting results.

3. The anti-filtration capacity and mechanical strength of set grout are not always decreasing along the direction of grout dispersion.

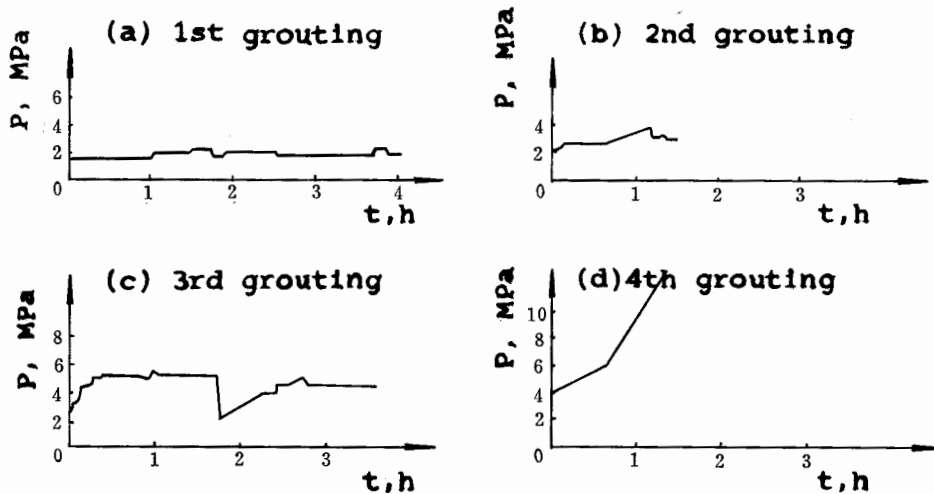


Fig.3 Grouting pressure vs time curve of each grouting run in 3# grout hole
 p- grouting pressure, t - grouting time.