7 - DEVELOPMENT OF LOW ALKALINE CEMENTITIOUS GROUTING MATERIALS FOR A DEEP GEOLOGICAL REPOSITORY

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Introduction

In order to reduce uncertainties of long-term safety assessment for a High Level radioactive Waste (HLW) repository system, low alkaline cementitious grouting materials has been studied. The pH of the leachate from the grouting material is targeted to be below 11.0, since the degradation of the bentonite buffer and host rock is limited.

The current work focused on the effects of pozzolanic reactions to reduce pH and the development of low alkaline cementitious injection materials in which super-micro ordinary Portland cement (SOPC) was partially replaced by silica fume (SF), micro silica (MS) and fly ash (FA).

Grouting of rock masses deep underground requires a good knowledge of the basic properties of the grouting material such as strength, resistance to segregation, fluidity, and etc. Furthermore, it is vitally important to realize how the grouting material will respond to a high injection pressure into the fracture. Thus, in order to understand the penetrability of different low alkaline cement mixes and to observe their flow behavior through the fracture, injection tests were conducted by using a simulated model fracture of 2 m diameter made from parallel plates of acrylic acid resin and stainless steel.

Experimental results of the basic properties for selecting suitable materials and that of injecting into a simulated fracture to assess the grouting performance are described in this study.

Basic Property Tests and Suitable Mix Proportions

Selection for Mix Proportions

According to the target values in the flowchart shown in Figure 1, 10 different mixes of SOPC, SF, MS and FA were selected with the addition of a superplasticizer (SP). Basic property tests of all 10 of the cement mixtures were investigated experimentally as described by the following:

Strength

Several mix proportions were subjected to fall-cone tests and uniaxial compression tests. The results demonstrated that water binder (cement + pozzolan) ratios in weight = 1.0 - 2.0, and SOPC/SF/MS/FA ratios of 5/5/0/0 and 4/5/1/0 were suitable mix proportions. The desired early age strength, shear strength and compressive strength development were achieved. Compressive and shear strength are shown in Figure 2.

Resistance to Segregation

All the mix proportions had a low bleeding ratio under the target value of 2 %. Under high pressurized condition, 2.0MPa, more bleeding was observed.

Fluidity

Rheological properties such as the plastic viscosity and yield value were measured with a rheometer after 30 minutes of mixing the materials. Rheological properties of selected 10 mix are shown in Figure 3. Although 50 mPa・s is generally required as a target viscosity, 100 is set in this study. Lower viscosity is difficult in low alkaline grout due to fine particle such as silica fume.

Given the required properties described above, 10 mix proportions with a SP were found to be the most promising and suitable for grouting.

Figure 1: **Flowchart of selection criteria for suitable mix proportions**

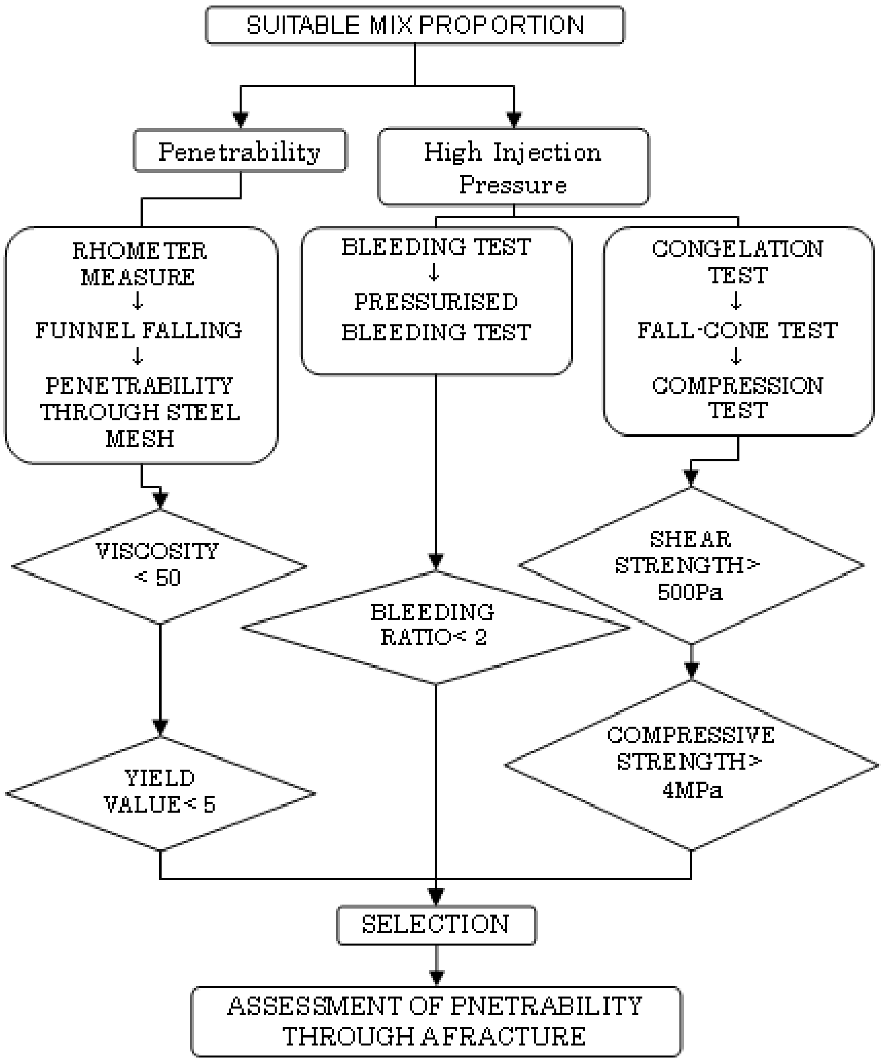


Figure 2: **Compressive and shear strength of selected 10 mix proportions (Red line:Target value)**

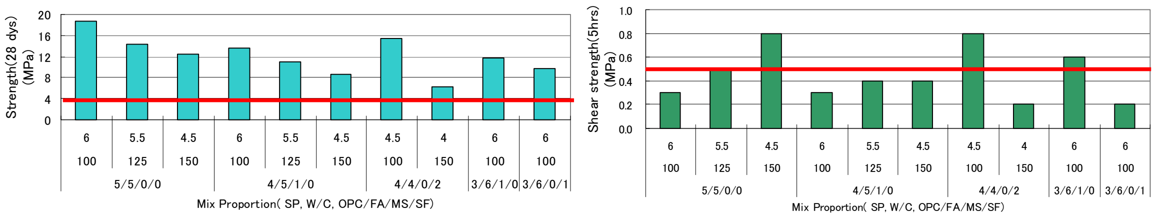
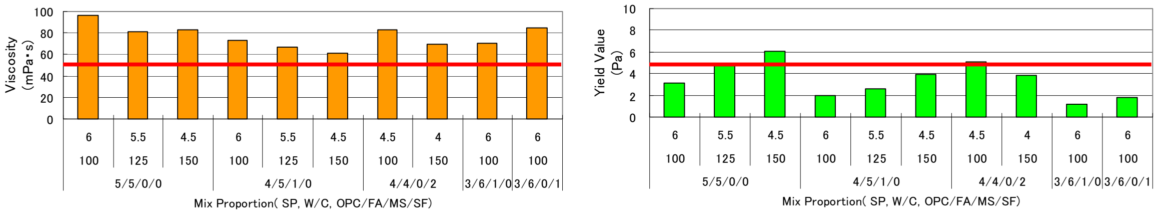


Figure 3: **Rheological properties of selected 10 mix proportions (Red line:Target value)**



Penetration Test Using a Simulated Model Fracture

Test Equipment and Procedures

The overall setup is shown in Plate 1. To directly observe the penetrating behavior of the cementitious materials, the upper surface disk is an acrylic acid resin of 2 m diameter and 5 cm thickness and the lower surface disk is steel and of the same dimensions. The aperture is controlled by a spacer. Against the high injection pressure, a confining steel frame of 70mm thickness is connected to the lower steel disk by 48 bolts.

The used grouting system consisted of:

- mixer: High shear Colloidal Mixer (TOYOSYOJI Co., Ltd. attached inverter. Maximum rev speed 2,100 rpm)
- agitator: 40 liter tank with stirring fan
- pump: servo-controlled injection pressure, maximum 10 liter per minute
- measurements: injection grout volume and pressure at the outside the injection hole, pressure distribution in the model fracture by 12 pressure sensors installed in the lower steel disk, continuous digital images of all the tests taken by CCD camera set 3 m above the simulated model fracture.

Testing Procedure and Cases

The testing procedure of the grout includes:

- Apertures of the simulated fracture were created with thin plate spacers having 0.1mm, 0.05 mm, and 0.02 mm thickness. Water injection tests were done prior to each grout injection test to assess the quantity of water leaking from the system, thereby confirming the constancy of the test equipment and the reliability of the results.

- Effects of injection pressure, three cases of injection pressure such as 0.1 MPa, 1.0 MPa, and 2.0 MPa were done.

Radial flow though the model fracture was observed by CCD camera and measured injection volume and pressure and pressure in the fracture.

Plate 1: **Overall Experimental setup.**
Birds-eye view of the Parallel Plate Fracture Model and Experimental System

Test Results

In order to know how the grout propagates and spreads in the model fracture, we show observational results of the typical two cases, in which one had complete penetration of grout throughout the entire fracture (Plate 2) and another case in which penetration was limited (Plate 3). The ratio of SOPC/SF/MS/FA in these tests was 5/5/0/0 and 3/6/1/0, respectively. The flow behavior through the model fracture was determined by pressure sensors installed in the lower steel disk, the results of which are shown in Figures 2 and 3. These results were obtained under the same conditions; a fracture aperture of 0.05 mm and an injection pressure of 2.0 MPa. Penetration into the fracture progressed mainly during the increasing injection pressure stage (< 80 seconds) followed by a decline in inflow and pressure during the constant injection pressure stage (> 80 second). It is proposed that friction loss and deformation of the fracture near the injection hole had a large effect on the injected grout. Furthermore, Newtonian fluids and the transient consistency properties of grouts will also have to be considered to predict grout propagation and spread.

Recommendation Proportion

In order to assess grouting performance into the fractured rock, 10 mix proportions were selected based on the basic properties such as strength, resistance to segregation, and fluidity and subjected to the injection tests into a simulated fracture. In the experimental investigations, penetration into the fracture of all the mixtures progressed mainly during the increasing injection pressure and the ratios of SOPC/SF/MS/FA =5/5/0/0 was more penetrable than the other mix proportions. And it is recommended that water binder ratio can be decided to fulfill the required strength. In this study, 100% at minimum W/B is applicable to inject the required small fissure.

Therefore, it is recommended that the ratio of SOPC/SF/MS/FA is 5/5/0/0 and W/B is 100% as a suitable proportion of low alkalinity cementitious grouting material.

Acknowledgement

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Plate 2: **Complete penetration of grout** Plate 3: **Limited infilling of the model fracture**
through the model fracture

Figure 2: **Examples of the relation between time and inflow rate, injection pressure, and pressure in the fracture OPC/SF/SS/FA/(W/B)=5/5/0/0/150,fracture aperture=0.05 mm**

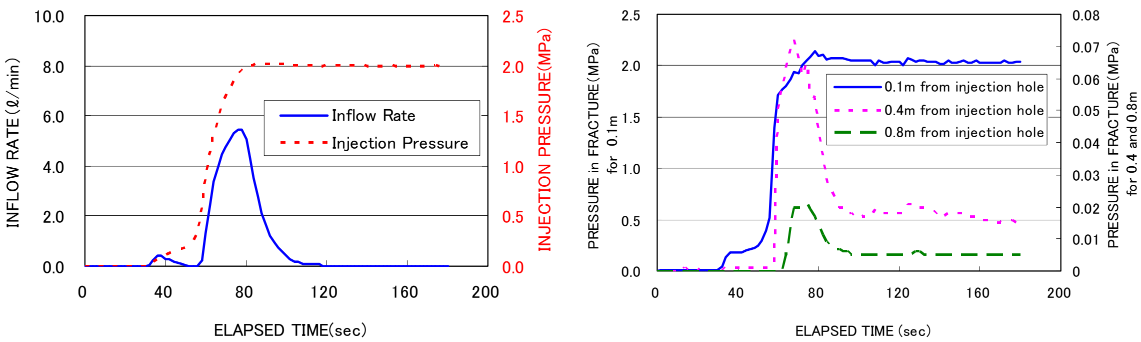

Figure 3: **Examples of the relation between time and inflow rate, injection pressure, and pressure in the fracture OPC/SF/SS/FA/(W/B)=3/5/1/0/100,fracture aperture=0.05mm**