Experimental Study on Characteristics of Penetration into Microcrack Depending on Viscosity

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***Abstract*— Grout method is used for the purpose of reinforcement or cutoff by injecting thickener into the ground or structure. Recently, it's also used to prevent the leakage by filling the cracks during tunnel excavation. The deeper the tunnel the less the cracks in the rock for excavation and the leakage would possibly occur through microcrack. A plane parallel plate injection device that simulates the microcrack was fabricated to test the clogging. Less clogging was occurred in microcrack with polymeric injection material even in case of higher viscosity, resulting in relatively stable injection because of less variation in injection volume. When using cement as injection material, adjusting the viscosity and minimizing the cohesiveness of cement particles are more than important and thus mechanical and chemical process to prevent the cement from being cohered is considered essential in grouting process. This study is intended to identify the clogging depending on change to viscosity with regard to micro cement and polymeric injection material which have been used for repairing and reinforcing the microcrack.**

***Index Terms*— Micro cement, polymeric injection material, microcrack, grouting**

I. Introduction

Grouting refers to the process of injecting solidifying agent including cement into the ground or structure for the purpose of reinforcement or cutoff. It's been commonly applied to the rock layer with discontinuous face such as joint in a bid to protect the steep slope and also is injected into the cracks in concrete structure for repairing.

Grouting was first applied in 1802 in France by using clay and lime suspension to fill the cavity below sluice gate and reinforce the surrounding alluvial layer and in 1887, a liquid injection material using sodium silicate and calcium chloride was developed and since 1900s, grouting technologies have been further enhanced in line with the development of equipment including pump and in Korea, foreign engineers first used in 1960's for foundation of multi-purpose dams and has been used widely for underground structure including subway construction[1]. Recently, its use has been further widened to restoration or reinforcement of the ground suffering the land subsidence.

Grouting material is categorized into cement suspension type, colloid type and liquid type and injection method is categorized into low pressure injection and high pressure injection depending on kind of material and the condition of the ground or structure for grouting, which may be determined at the site. How to make design-mixed solidifying agent reach to the specific point is the key in this method.

Various studies have been conducted in Korea in an effort to improve the injection performance. Mr. Jeon conducted the study on grout fluidity and injection pressure depending on joint roughness and gap change[2]. Mr. Kim introduced the plane parallel plate injection test to evaluate the cement injection characteristics so as to assess the injection performance depending on gap and crack[3] and Mr. Lee attempted to improve the penetration performance through improvement of injection method in a way of vibrating the grout material injection tube, which was the typical cases of enhancing the grouting material and injection method[4].

But in previous studies, evaluation of microcrack less than 0.25 mm was not conducted. In fact, expensive micro cement or polymeric material is sometimes used to deal with microcrack at repair or restoration site and microcrack larger than micro cement was reportedly clogged with such injection material and the study to come up with the solution is underway.

This study is intended to identify the clogging depending on viscosity variation with regard to micro cement and polymeric injection material which have been widely used domestically for repairing and reinforcing the microcrack. A plane parallel plate injection device that could simulate the microcrack was fabricated and test was conducted with micro cement and polymeric injection material. As various polymeric injection materials with different functions and types are available, polymeric viscosity agent which has been commonly used for grouting was used to produce the specimen with same viscosity used for micro cement test and the test was conducted with two types of material with different fundamental characteristics.

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II. Grout Injection Performance Test

A. Figures and Tables

Grouting applied to the cracks is for urban site requiring precise reinforcement and since it needs to deal with the cracks developed irregularly, applicability of grout material and injection method shall be proven in advance. Then grouting injection performance test generally adopts column or pipe injection device to avoid disrupting the soil particle structure. But as it's difficult to quantitatively simulate the cracks, plane parallel plate device with open outlet is more rational than column type device.

As this study is intended to evaluate the performance of grout material which is injected microcrack, plane parallel plate (Fig. 1.) meeting the test requirements was used for the test. A plane parallel plate device comprises of pressurizer, grount injector, pump, parallel plate, flow gauge to measure the flow per unit time and data logger. To simulate the cracks in ground, industrial film (polyester film, heat shrinkage 1% or less, elastic coefficient 450kgf/mm^2) was used so as to simulate the ground material penetrating into the cracks in rock. As seen in Fig. 1, Film is applied to A to maintain the crack width constantly and then the grout material moves through B. To measure the pressure generated from grout pump to the ground, three pressure gauges were set at inlet and two intermediate points (3.1 and 2.3 point of plane parallel plate) Acrylic plate was set on top to check the clogging point, if any, and pressure cell and ground crack were designed to allow the pressure up to 1,000 kPa.

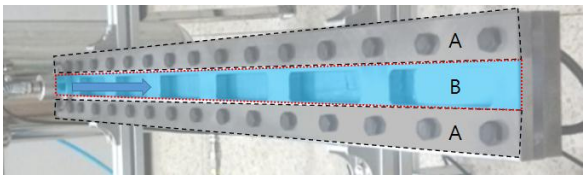

Figure 1. Injection equipment of parallel plate

B. Micro Cement

Since injection effect of ordinary portland cement was verified, chemical liquid injection began to be introduced in earnest, but due to large grain size, on average and 15~20 ㎛ in maximum, injection range was limited which caused the low penetration effect of cement material[5]. To deal with such problems, micro cement with smaller grain size was introduced, despite of high cost and has been widely used to deal with microcrack.

Fineness of micro cement used in this study was 8,000 and cement grain size was 5 ㎛ on average and 25 ㎛ in maximum And cumulative grain size distribution and grain size distribution curve provided by the manufacturer (see Chemius Korea web site) is as Fig. 2.

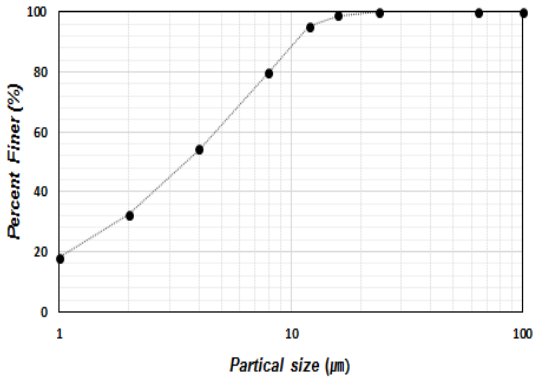

Figure 2. Grading curve of Micro cement

C. Thickener

Various types of polymeric injection material are available to use for particular use such as reinforcement or cutoff and the study focused on identifying the basic properties of polymeric injection material using polymeric thickening agent. Thickener used in this study was cellulose water-soluble polymer which is commonly used at construction site or for ground reinforcement grouting. Cellulose used has 30~65% crystalline properties due to intermolecular hydrogen bonds and is insoluble natural polymer, but is produced as cellulose ether through Etherification which is modified to water-soluble polymer.

D. Test Summary

Considering the water-cement ratio for grouting is usually200%, water-cement ratio 85%, 130% and 250% were used. To identify the relationship with viscosity which is considered the influential factor on cement penetration performance, the specimen having same viscosity as micro cement mixing ratio used for the test was produced for injection test. Fig 3 shows micro cement mixing ratio - viscosity relationship and Fig 4 shows thickener mixing ratio - viscosity relationship. And mixing ratio for same viscosity is as Table 1.

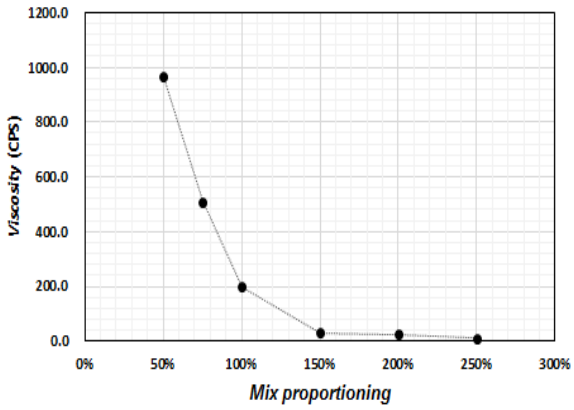

Figure 3. Mixing ratio-Viscosity Curve (Micro cement)

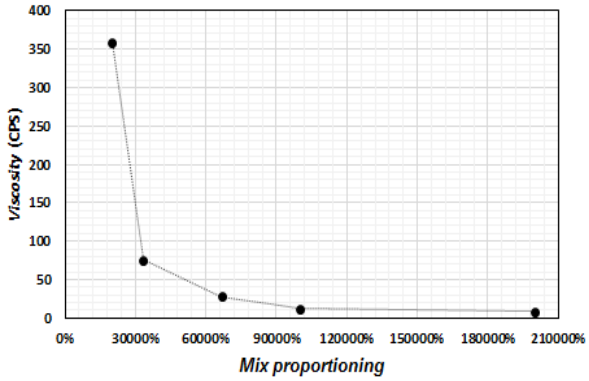

Figure 4. Mixing ratio-Viscosity Curve(Thickener)

TABLE I. MIXING RATIO

Division	Viscosity(cps)		
	12	76	359
Micro cement	250%	130%	85%
Thickener	100,000%	66,667%	20,000%

The injection test using distilled water and grout material such as micro cement with thickener was conducted, respectively. Ground crack width was adjusted by industrial film with the thickness, 0.016 ㎜, 0.025 ㎜, 0.038 ㎜, 0.075 ㎜, 0.25 ㎜ and 0.35 ㎜ The test was conduced while increasing the crack interval by double and in case of micro cement, 0.125 ㎜, 0.25 ㎜, 0.5(0.25 ㎜ × 2 sheets)㎜ and 1.05(0.35 ㎜ × 3 sheets) ㎜ were applied and crack width 0.075 ㎜, 0.125 ㎜ and 0.25 ㎜ were applied for thickener. For each crack width, distilled water produced at the lab was used for comparison with the cases without adding grout material.

After making inside saturated by injecting the water into plane parallel plate, grout material mixed with water was agitated at constant speed. It's pressurized upon mixing so as to avoid the part of grout material being precipitated or clogged during extended test time. Injection pressure was maintained at 50kPa in accordance with Japanese soil engineering standard, 50 ~ 100 kPa, because no domestic standard is available[6]. When the grout material is discharged through the cracks in plane parallel plate, discharge volume was measured by electronic scale. To maintain the unifomity and reproducibility of the test, lab temperature and HR were maintained at 20℃ and 50~70% and distilled water was used.

III. TEST RESULT

A. Distilled Water Injection Test Result

In case of using distilled water, it passed all the cracks simulated by plane parallel plate, Fig 5 shows crack width - penetration/ unit time relationship. In case of using distilled water, penetration per unit time in cracks less than 0.1 ~ 0.2 ㎜ was rapidly reduced. In case of the largest width 1.05 ㎜ used for the test, penetration was about 1tom. The test result with distilled water could be compared with the test using grout material as the basic data for plane parallel plate.

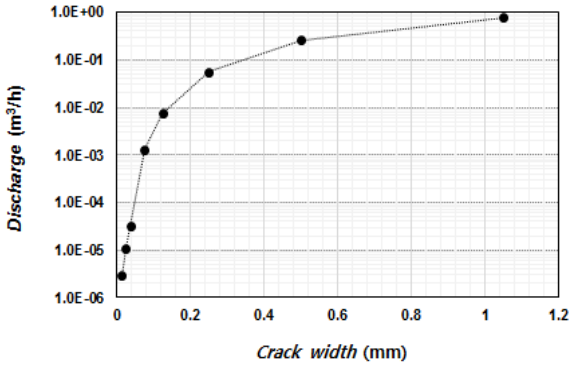

Figure 5. Creak width and Discharge(Water)

B. Micro Cement Injection Test Result

Fig 6 shows the test result after mixing micro cement at water-cement ratio to produce the certain viscosity in penetration per crack width - unit time relationship. Each result was indicated irrespective of clogging or not and penetration per unit time till the change on pressure gauge was monitored because of clogging. When it comes to 12cps with crack width 0.125mm, only 14.5% penetrated comparing to the case using distilled water and with crack width 0.25mm, 45.8% penetrated successfully. When it comes to 76cps with crack width 0.25mm, 16.8% penetrated comparing to the case using distilled water and with crack width 0.5mm, 40.1% penetrated successfully. When it comes to 359cps with crack width 0.5mm, 11.8% penetrated comparing to the case using distilled water and with crack width 1.05mm, 62.0% penetrated successfully. In case of clogging, 14.4% only penetrated comparing to the penetration per unit time when using distilled water and in case of no clogging, 49.3% penetrated on average when comparing to the case using distilled water.

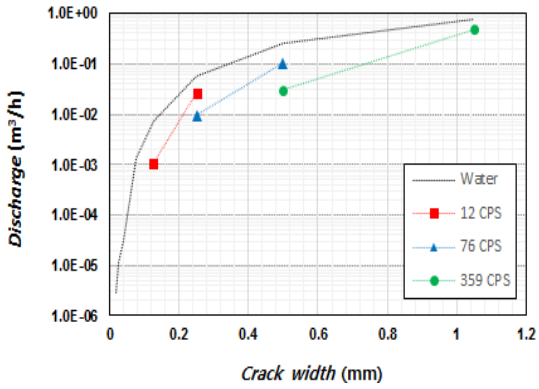

Figure 6. Creak width and Discharge(Micro cement)

C. Thickener Injection Test Result

Thickener was adjusted to have same viscosity as micro cement for the test. When using the thickener, the

viscosity was same as micro cement, but a liquid type was rather suitable to microcrack and the grain size was smaller than micro cement particle and costly but injection performance was superior. Fig 7 shows the test result using thickener in penetration per crack-width - unit time relationship. When it comes to 12cps with 0.075mm, 0.125mm and 0.25mm, 18.2%, 31.0% and 8.3% of penetration was monitored when comparing to the case using distilled water. When it comes to 76cps 0.075mm, 0.125mm, 0.25mm, 67.5%, 10.4% and 4.3% of penetration was monitored when comparing to the case using distilled water. When it comes to 359cps with 0.075mm, 0.125mm, 0.25mm, 1.0%, 33.7%, 3.8% and 20.8% of penetration was monitored when comparing to the case using distilled water. Comparing to 0.125mm when clogging occurred, 0.25mm without clogging was increased by double with 12 cps and 3 times with 76cps. In case of using the thickener with crack width without clogging. penetration rate was 11.1% on average comparing to the case using distilled water.

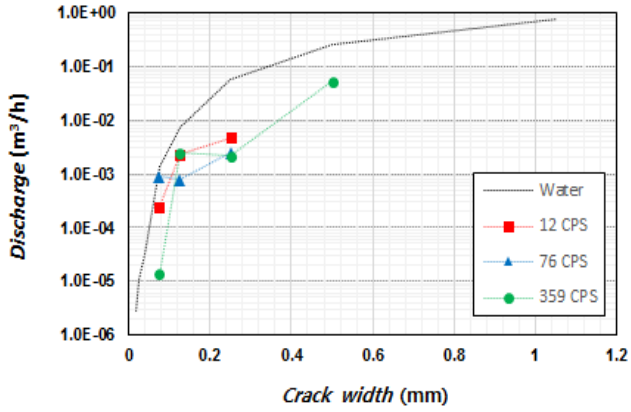

Figure 7. Creak width and Discharge(Thickener)

D. Viscosity

Fig. 8 shows the relationship between viscosity and penetration per unit time when using micro cement and Fig. 9 shows the relationship between viscosity and penetration per unit time when using the thickener. Eq. (1) and Eq. (2) show the viscosity - penetration per unit time relations.

$$Y = 0.0086\, e^{0.0077X} \quad (1)$$

$$Y = 0.0013\, e^{0.0002X} \quad (2)$$

Injection volume of micro cement was larger than the thickener at same viscosity, but clogging was occurred in microcrack, while clogging was less in microcrack and no significant variation was monitored when using the thickener and thus more stable in general and injection performance was superior to micro cement.

Grain size of micro cement used for the test was 5 ㎛ on average but the clogging was occurred in 125 ㎛ crack. Should the viscosity be maintained constantly, no clogging shall occur considering the uniform grain size distribution, and thus micro cement particle aggregated while the flow velocity and pressure are reduced would possibly block the crack. Such clogging may prevent the grout material from being transferred to the specific point but may cause it to be isolated in the middle.

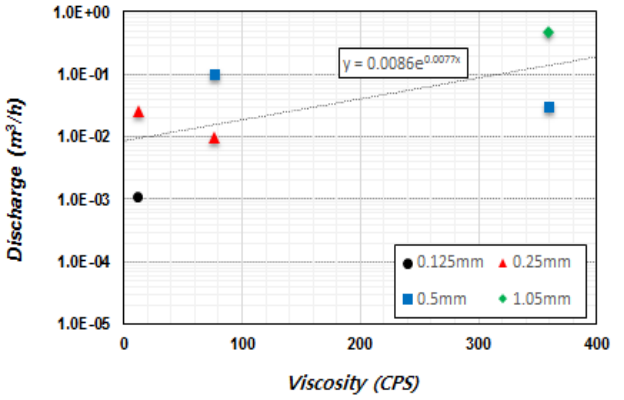

Figure 8. Viscosity and Discharge(Micro cement)

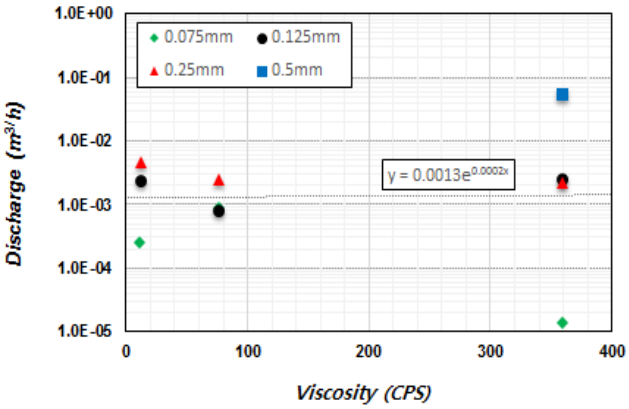

Figure 9. Viscosity and Discharge(Thickener)

E. Determination of Injection Range through Plane Parallel Plate Test

Fig 8 shows the relations between micro cement injectable crack width and the viscosity which was obtained from plane parallel plate test and clogging part is defined in Fig 8. According to the study by Nishikaki indicated in Fig 10 and 11, injection performance of ordinary portland cement was superior to micro cement, which was attributable to fine grain of micro cement that causes more aggregation than portland cement. Injection performance of domestic micro cement was slightly poorer than the values in reference data[7].

When using the cement as injection material, it's more important to reduce the aggregation instead of reducing the grain size of cement..

Injection efficiency at the site is dependent on various factors such as roughness of crack, ground conditions and others and thus applying the lab test result to the site would be difficult but it would help identify the injection performance approximately which could be used for grouting design or estimating the injection range.

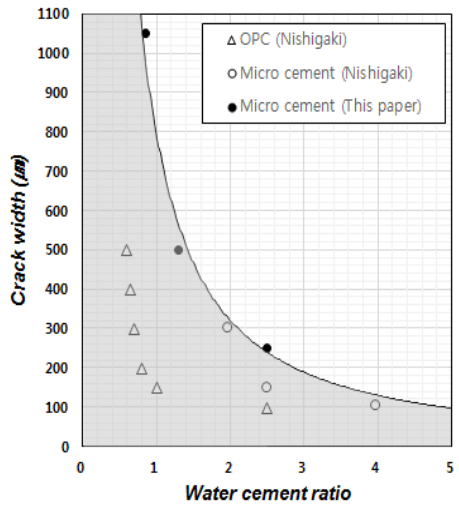

Figure 10. Water cement ratio and Crack width(Micro cement)

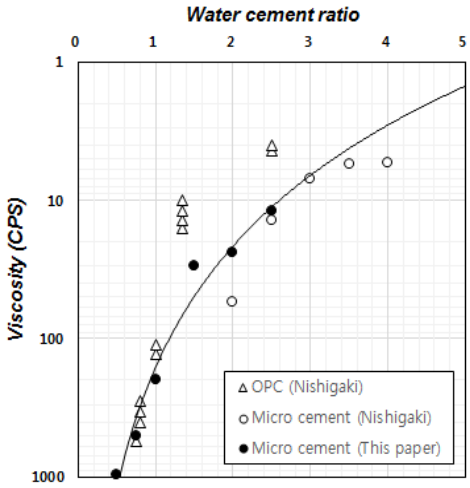

Figure 11. Water cement ratio and Viscosity(Micro cement)

IV. Conclusion

To evaluate injection performance in microcrack depending on viscosity of grout material, the test was conducted using distilled water, micro cement and the thickener and consequently, following conclusion was made.

1. When using micro cement, penetration rate was 49.3% on average comparing to the case using distilled water in the cracks without clogging. And when using the thickener, penetration rate was 11.1% on average comparing to the case using distilled water in the cracks with clogging

2. Injection volume of micro cement was larger than the thickener at same viscosity bit clogging was monitored in microcrack, while less clogging was monitored in microcrack when using the thickener and injection variation was insignificant even in case of increased viscosity, indicating the relatively stable injection performance.

3. Unlike the data known generally, using micro cement alone as injection material indicated the poorer injection efficiency than portland cement. When using the cement as injection material, it's important to minimize the aggregation of cement particles in addition to adjustment of viscosity. Thus mechanical or chemical process to prevent the micro cement from being aggregated is required when applying the grout method.

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