

Experimental Study on Thermo-mechanical properties of Backfilling Grout for Close-loop Vertical Ground Heat Exchanger

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ABSTRACT: Thermo-mechanical properties of grout materials have been investigated, which are used for backfilling a ground heat exchanger in the geothermal heat pump (GHP) system. The thermal conductivity and viscosity of nine different bentonite grouts and a cementitious grout with various mix proportions have been considered in this study. The bentonite grouts indicate that the thermal conductivity and viscosity increase with the content of bentonite or filler (silica sand). In addition, material segregation can be observed when the viscosity of grout is relatively low. The saturated cement grouts appear to possess much higher thermal conductivity than the saturated bentonite grouts, and the reduction of thermal conductivity by drying the cementitious grout is less than the case of the bentonite grouts. Maintaining the moisture content of grouts is a crucial factor in enhancing the efficiency of ground heat exchangers.

Keywords: ground heat exchanger, bentonite grout, cementitious grout, thermal conductivity, viscosity

1. INTRODUCTION

The efficiency of heat exchange in a close-loop vertical ground heat exchanger is one of the most crucial factors to enhance the geothermal heat pump (GHP) system. Influence factors on heat exchange can be the thermal conductivity of backfilling grout and HDPE pipes, heat interference between the pipes, the thermal conductivity of adjacent geologic formations. In this paper, thermo-mechanical properties of grout materials, i.e., thermal conductivity and viscosity, have been investigated, which are used for backfilling the ground heat

exchanger. The backfilling grout should be used not only to seal the annulus between the borehole and heat exchanger loop but also to exchange properly heat between the ground formation and the loop.

Increase in the thermal conductivity of backfilling grouts leads to considerable reduction in installation cost for ground heat exchanger by shortening the required bore length. In addition, acceptable groutability of grouts should be guaranteed during the installation of the heat exchanger in order to fill completely the annulus without any gaps that may cause thermal discontinuity.

The thermal conductivity and viscosity of nine different bentonite grouts from

different producers have been experimentally evaluated in case of both neat bentonite grouts and thermally enhanced bentonite grouts with addition of silica sand as a filler. In addition, a phenomenon of material segregation was observed when the viscosity of the thermally enhanced bentonite grout was low.

Cementitious grouts as an alternative grout material (Allan, 2000; Allan and Philippacopoulos, 2000) with various mix proportions have been considered in this study. Allan and Philippacopoulos (1999, 2000) reported a series of experimental results on the thermal conductivity of cementitious grouts and proposed an optimized cementitious grout formulation, namely Mix 111, which enhances thermal conductivity. The cementitious grouts are relatively inexpensive, safe and easy to work. The thermal conductivity and viscosity of cementitious grout have been investigated and compared to the thermo-mechanical properties of bentonite grouts.

2. MATERIALS

Nine bentonite grouts provided by three different producers in Korea have been chosen for this study. The fundamental properties of each grout are summarized in Table 1. Bentonite 1 is a low grade bentonite used for a casting process, and Bentonite 2 is improved by adding montmorillonite to increase swelling potential. Bentonite 3, 4, and 5 are produced for the purpose of civil engineering construction such as a mixture for a landfill liner or bentonite slurry. Especially, Bentonite 5 possesses very high viscosity and swelling potential but is more expensive than the other grouts. Bentonite 6 is used in constructing a landfill liner. Bentonite 7 is a granular product and used in waterproofing. On the contrary, Bentonite 8 is powdered and produced for geothermal application. In particular, Bentonite 9 includes silica sand to an extent during manufacturing process to

enhance the thermal conductivity. Silica sand was used as a filler of which gradation curve is shown in Figure 1.

Considering the cementitious grout, potland cement was selected as a main grouting material with mixture of the silica sand used in the bentonite grout as a filler, and a small amount of bentonite was added for preventing the bleeding or segregation of the cementitious grout.

Table 1: Fundamental physical properties of bentonites

Bentonite	Producer	Water Content (%)	Swelling Index (ml/2g)	pH
1	D	10.0	12-15	9-11
2	D	10.0	24-30	9-11
3	S	8.9	15.0	10.0
4	S	9.5	23.0	10.1
5	S	9.5	24.5	10.0
6	C	12.0	18.0	6-12
7	C	12.0	29.0	6-12
8	C	12.0	10.0	6-12
9	C	12.0	11.0	6-12

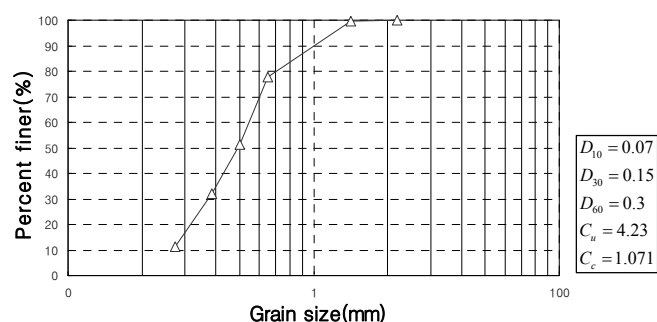


Figure 1: Gradation curve of silica sand.

3. EXPERIMENT

2.1 Thermal Conductivity

The thermal conductivity of grouts was measured using QTM-500K thermal conductivity meter (Kyoto Electronics) which is equipped with PD-13 probe of which dimension is 95 mm × 40 mm. The equipment adopts the transient hot wire method to measure the thermal conductivity of grout material.

Because the bentonite grout paste is amorphous, an acrylic container box was devised to fill the paste in it and to permit the measurement of thermal conductivity. The container box consists of a water jacket, a perimeter passage, which is connected to a water tank to flow water of controlled temperature through it, and thus a room temperature of 20°C is presumably maintained in bentonite grout specimens during measuring thermal conductivity.

After curing the cementitious grouts in a rectangular mold for 14 days, the thermal conductivity of both the wet and air-dried specimens were measured using the QTM-500K thermal conductivity meter.

2.2 Viscosity

The viscosity of bentonite grouts was measured by a vibration-type viscometer of which measuring plate vibrates with a frequency of 30 Hz. The viscosity range measurable in the viscometer is from 0.003 to 120 P. In order to investigate the isothermal change in viscosity with time after mixing bentonite grouts, a similar acrylic container box to that used for measuring thermal conductivity was devised, which is also equipped with a water jacket to flow water at a room temperature of 20°C.

Viscosity of cementitious grout paste was indirectly estimated by flowability. It is measured by both the V-Funnel test and the slump flow test.

4. RESULTS

4.1 Bentonite Grout

When bentonite is used for backfilling the ground heat exchanger, 15% to 25% bentonite by weight is usually mixed with water. Therefore, two mix proportions of 20% and 30% bentonite by weight were chosen to investigate the thermal conductivity of the nine neat bentonite grouts with no addition of fillers. Figure 2

compares the measured thermal conductivity of each neat bentonite grout in the fully saturated condition. In case of 20% bentonite by weight, the thermal conductivity lies in a narrow range of 0.74-0.81 W/m°C. For 30% bentonite case, the range of thermal conductivity is 0.76-0.95 W/m°C.

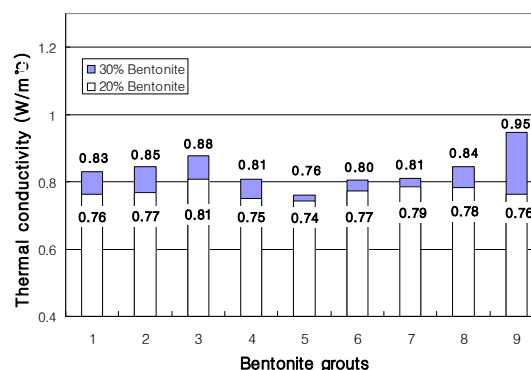


Figure 2: Thermal conductivity of neat bentonite grouts

After air-drying the specimens for 10 days, the thermal conductivity of the dried bentonite grout was measured to show how much thermal conductivity decreases by drying process, which may represent a situation of groundwater table drawdown. In the case of 30% bentonite, the thermal conductivities of Bentonite 1 and 2 were substantially reduced from 0.83 to 0.27 W/m°C and from 0.85 to 0.31 W/m°C, respectively. Note that maintaining bentonite grout saturated should be required to avoid unpredictable reduction of heat conduction performance of underground heat exchangers.

The thermal conductivity of bentonite grouts can be enhanced by the addition of a small amount of fillers such as silica sand (Han et al., 2005). For the two cases of bentonite content (20% and 30%), the improvement of thermal conductivity by the addition of silica sand was investigated. The amount of added silica sand was 15, 30, 45, and 60% of bentonite by weight. Figure 3 shows the variation of thermal conductivity for the case of 20% bentonite content. At

each 15% increase of silica sand content, the thermal conductivity increased by 0.08-0.12 W/m°C on the average. A similar tendency can be observed for the case of 30% bentonite content as shown in Figure 4. The result indicates that the increase in the thermal conductivity due to the addition of silica sand is not significant, and even the case of 60% of silica sand results in the thermal conductivity less than 1.4 W/m°C.

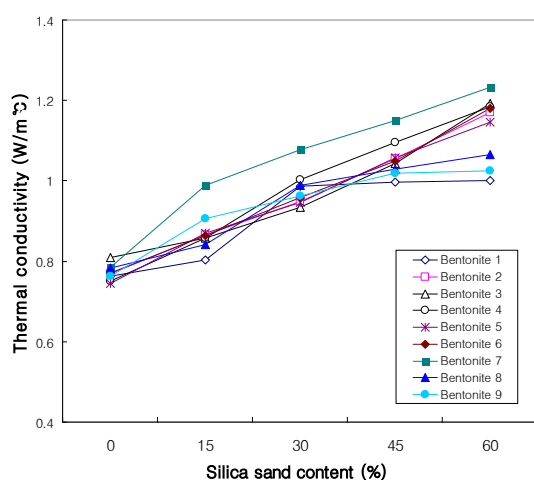


Figure 3: Thermal conductivity of 20% bentonite grout with various contents of silica sand

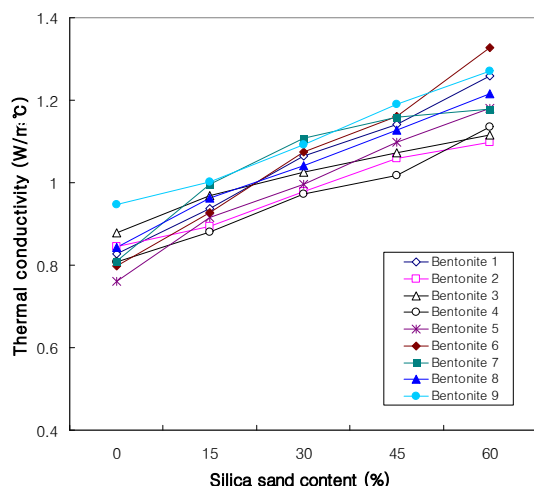


Figure 4: Thermal conductivity of 30% bentonite grout with various contents of silica sand

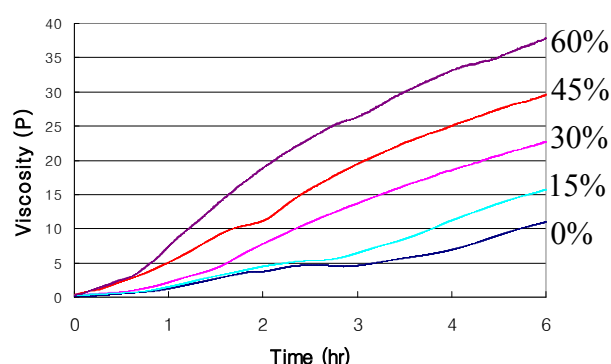
In case of the 20% bentonite in Figure 3, the thermal conductivity of Bentonite 1 increases to a maximum value at the silica sand content of 30% and then is kept to the

value. The reason for this can be explained by a phenomenon of material segregation. Bentonite 1 possessed the lowest viscosity at the same bentonite content compared to the other bentonite grouts, and thus the silica sand mixed in the Bentonite 1 grout paste settled down and separated from the bentonite paste. Settled silica sands were observed at the bottom of the container as shown in Figure 5.

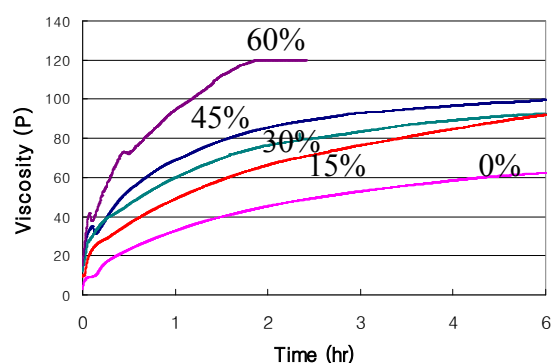


Figure 5: Settled silica sand at the bottom of container

The viscosity of bentonite grouts after being mixed with water should increase with time due to the rheological characteristic (Choi et al., 2008). A considerable increase in viscosity can make pumping grout difficult during installing ground heat exchangers. In this paper, a change in viscosity with time has been quantitatively investigated for two bentonite grouts, Bentonite 1 and 3, with the bentonite content of 20%. In this comparison, the effect of magnitude of mixed silica sand was also examined. Figure 6 shows the significant increase in viscosity with time for 6 hours. In addition, the rate of viscosity increase becomes greater when the amount of silica sand mixed in the grout increases. Especially, the viscosity of Bentonite 3 mixed with 60% of silica sand reaches the measurement limitation of the viscometer (i.e., 120 P). Therefore, care must be taken not to delay significantly grout pumping operation after preparing the grout paste in the field.



(a) Bentonite 1 (20%)



(b) Bentonite 3 (20%)

Figure 6: Comparison of increase in viscosity with time

4.2 Cementitious Grout

Allan and Philippacopoulos (1999, 2000) reported from a series of laboratory tests that the thermal conductivity of neat cement grout ranged from 0.80 to 0.87 W/m°C. In addition, an optimized grout formulation, namely Mix 111, yielded the thermal conductivity of up to 2.42 W/m°C. The grout consists of cement, water, a particular grade of silica sand, superplasticizer, and a small amount of bentonite.

In this paper, the role of influence factors such as water/cement ratio, silica sand/cement ratio, and bentonite dosage on the thermal conductivity and viscosity of cementitious grouts has been investigated. The experimental results are as follows:

(1) Water/cement ratio

Five different mix proportions for neat cement were prepared by only varying the water/cement ratio as 0.4, 0.5, 0.6, 0.7, and 0.8, as shown in Table 2 and thermal conductivity and viscosity with time were measured on the specimens. The measured thermal conductivity and slump flow for the five mix proportions are described in Figure 7. Increasing the water/cement ratio leads to a decrease in thermal conductivity and an increase in slump flow which means the enhancement of flowability. The thermal conductivity decreases by 0.01 - 0.07 W/m°C with the increment of water/cement ratio of 0.1. When the specimens were air-dried, the thermal conductivity was reduced only by around 0.25 W/m°C. This reduction is far smaller than the case of bentonite grouts, and thus the cementitious grout may be less vulnerable to a drying condition due to water table drawdown.

Allan and Philippacopoulos (1999) reported that it is important to maintain a minimized water/cement ratio for increasing thermal conductivity and decreasing hydraulic conductivity. However, when it comes to groutability or pumpability, very small values of water/cement ratio with high viscosity can result in difficulty of pumping cementitious grout into the borehole. Accordingly, it is necessary to consider not only thermal conductivity but also viscosity in order to determine an optimized mix proportion for cementitious grouts.

Table 2: Effect of water/cement ratio and viscosity

Cement	Geo-1	Geo-2	Geo-3	Geo-4	Geo-5
w/c ratio	0.40	0.50	0.60	0.70	0.80
Slump	164-	220-	284-	350-	355-
Flow(mm)	168	231	288	355	385
V-Funnel(sec)	5.6	2.1	< 1	< 1	< 1

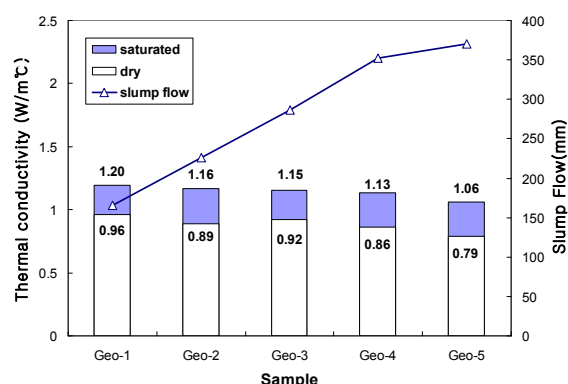


Figure 7: Thermal conductivity and slump flow with varying water/cement ratio

(2) Silica sand/cement ratio

Five different mix proportions with the water/cement ratio of 0.6 were considered with varying the silica sand/cement ratio as 2.0, 2.2, 2.4, 2.6, and 2.8, as shown in Table 3. In this case, a small dosage of superplasticizer is added to the mixture by 0.1% of cement weight to maintain proper groutability. The measured thermal conductivity and slump flow for the five mix proportions are described in Figure 8. Increasing the silica sand/cement ratio leads to an increase in thermal conductivity and a reduction in slump flow which decreases groutability. The thermal conductivity increases by 0.01 - 0.09 W/m°C with the increment of silica sand/cement ratio of 0.2. When the specimens were air-dried, the thermal conductivity was reduced by around 0.20 – 0.42 W/m°C that is far smaller than the case of bentonite grouts, and thus the cementitious grout mixed with silica sand may be less vulnerable than bentonite grout to a drying condition.

Allan and Philippacopoulos (1999) added a superplasticizer of about 8.8 litres per a unit volume (1 m³) of cementitious grout to assure suitable groutability. However, properties of superplasticizer should be different for each product, and it is difficult to characterize quantitatively the role of superplasticizer in cementitious grout mixed with silica sand.

Table 3: Effect of silica sand/cement ratio and viscosity

Cement	Geo-6	Geo-7	Geo-8	Geo-9	Geo-10
w/c ratio	0.60	0.60	0.60	0.60	0.60
Sand/cement ratio	2.00	2.20	2.40	2.60	2.80
Slump Flow(mm)	195–210	180–187	107–110	100	100
V-Funnel(sec)	2.5	2.6	4.5	300	300

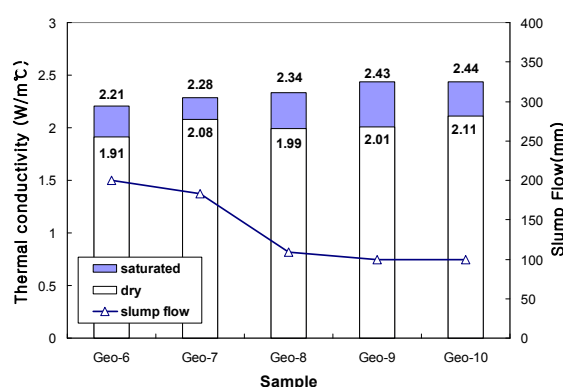


Figure 8: Thermal conductivity and slump flow with varying silica sand/cement ratio

(3) Bentonite content

Five different bentonite dosages with the water/cement ratio of 0.6 and the silica sand/cement of 2.4 were considered with varying the bentonite content of 1, 2, 3, 4, and 6% of cement weight as shown in Table 4. Allan and Philippacopoulos (1999) noted that the purpose of a small dosage of bentonite added into cementitious grouts was prevention from bleeding and the segregation of silica sand.

As can be seen in Figure 9, the bentonite content of 1 – 6% of cement weight does not affect significantly the thermal conductivity of cementitious grouts. On the contrary, the addition of a small amount of bentonite leads to a considerable reduction in the flowability of the grouts, that is, only 2% of bentonite made the value of slump flow

become the minimum value of 100 mm. When the specimens were air-dried, the thermal conductivity was reduced by around 0.34 – 0.44 W/m°C that is slightly larger than the case of no bentonite addition.

Table 4: Effect of bentonite addition and viscosity

Cement	Geo-11	Geo-12	Geo-13	Geo-14	Geo-15
w/c ratio	0.60	0.60	0.60	0.60	0.60
Sand/cement ratio	2.40	2.40	2.40	2.40	2.40
Bentonite/cement ratio	1 %	2 %	3 %	4 %	6 %
Slump Flow(mm)	105–107	100	100	100	100
V-Funnel(sec)	4.5	300	300	300	300

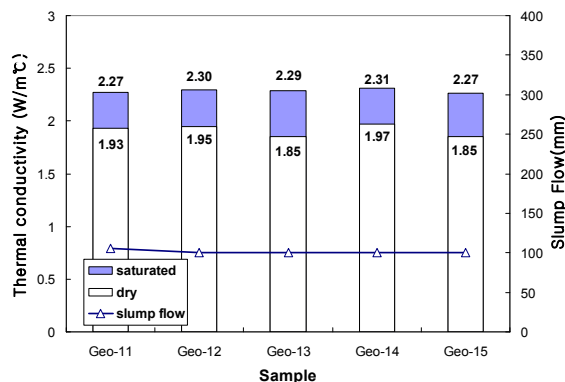


Figure 9: Thermal conductivity and slump flow with different bentonite content

5. CONCLUSION

The following conclusions are based on the findings for the thermal conductivity and viscosity of bentonite grouts and cementitious grouts

(1) In case of the nine neat bentonite grouts with no addition of fillers, two mix proportions of 20% and 30% of bentonite by weight show a range of thermal conductivity in the fully saturated condition of 0.74-0.81

W/m°C and 0.76-0.95 W/m°C, respectively, which are far smaller than the cementitious grouts. When the specimens are air-dried, the thermal conductivity significantly decreases. Increase in thermal conductivity due to the addition of silica sand is not significant, and even the case of 60% of silica sand results in the thermal conductivity less than 1.4 W/m°C.

(2) The viscosity of bentonite grouts significantly increases with time. The rate of viscosity increase becomes greater when the amount of silica sand mixed in the grout increases. It is highly recommended to be careful to prepare grout paste with no delay in the field when pumping it into the borehole.

(3) For neat cementitious grouts, increasing the water/cement ratio leads to a decrease in thermal conductivity and an increase in slump flow which means the enhancement of flowability. A reduction of thermal conductivity due to air-drying is about 0.25 W/m°C which is far smaller than the case of bentonite grouts, and thus the thermal conductivity of cementitious grout may be less vulnerable to a drying condition than the bentonite grouts.

(4) Addition of silica sand to cementitious grouts leads to an increase in thermal conductivity and a reduction in slump flow which decreases groutability. However, addition of a small dosage of bentonite does not affect significantly the thermal conductivity of cementitious grouts.

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REFERENCES

- [1] Allan, M. L. 2000. Material characterization of superplasticized cement-sand grout. *Cement and Concrete Research* 30. pp. 937-942.
- [2] Allan, M. L., Philippacopoulos, A. 1999. Properties and performance of cement - based grouts for geothermal heat pump application. FY 1999 Progress Report, BNL 67006, 53pp.
- [3] Allan, M. L., Philippacopoulos, A. 2000. Performance characteristics and modelling of cementitious grouts for geothermal heat pumps. *Proceeding of World Geothermal Congress 2000*. 10th June, Beppu and Morioka, Japan, pp. 3355-3360.
- [4] Choi, H., Lee, C., Choi, H-P, and Woo, S-B. 2008. A study on the physical characteristics of grout material for backfilling ground heat exchanger. *Journal of the Korean Geotechnical Society*. 24(1). pp. 37-49.
- [5] Han, J., Han, G., Han, H., and Han, C. 2005. Geothermal Heat Pump (GHP) System. in Korean. Han Lim Won.