Journal of Engineering and Applied Sciences 13 (19): 7783-7788, 2018
ISSN: 1816-949X

Effect of Magnetic Field Energy on Physical Properties of Ground Grouting

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Abstract: This study investigated the influence of magnetic field energy on surface tension, viscosity, flow velocity and hydraulic pressure of grout materials by using an electro-magnetic force generator. The various changes were measured using a specially manufactured magnetic field energy force device and a transfer device. The surface tension of distilled water after treated with magnetic field energy was found to decrease after about 1 h. As a result, the reaction area of the cement paste increased, hydration reaction was promoted and the viscosity and surface tension values decreased through the generation of surplus water molecules. To confirm that the magnetic field energy caused the flow efficiency to increase and hydraulic pressure to decrease due to the decrease in surface tension and viscosity, the grout material in the pipe was circulated and the hydraulic pressure was measured. The data confirmed that the hydraulic pressure decreased after applying the magnetic field energy. Furthermore, it was verified that the fluidity of the grout material improved due to the magnetic field energy.

Key words: Magnetic field energy, grouting, liquidity, cluster, surface tension, viscosity

INTRODUCTION

Recently, a great deal of research on grouting materials, instrument and technologies has been actively conducted in order to improve the performance of grouting. In terms of material development, super-fine-particle cement has been studied in Japan while micro-cement-based hybrid grouting materials have been developed in Republic of Korea. In addition in order to improve penetration and high strength of grout materials, development of their relevant instruments and technologies have been actively carried out both domestically and internationally. Furthermore, studies on grout penetration and transport technology have been broadly studied (Choi *et al*., 2013). The grout materials used for reinforcing the ground and constructing a hydraulic barrier have advantages of durability and stability but are limited by low permeability and low fluidity. These limitations result in a high concentration and high viscosity thereby causing poor micro-crack injection (Moonbok *et al*., 2015). Therefore, it is imperative to develop a grout material and injection device that satisfy the durability, stability and water repellency of the ground, simultaneously.

The cement suspension injection method has a wide range of applications, including embankment reinforcement, water repellency and landfill, construction with this method is very common. However, the injection of cement-based grout materials has a disadvantage in that it is difficult to inject into ground that is not granulated soil because the infiltration limitations and the filtration phenomenon prevents its injection into microparticulate pores or micro-pore gaps (Yea *et al*., 2010). In fact, Kim *et al*. (2015) have studied the change of fluidic characteristics in a controlled flow by applying a magnetic field to the fluid in order to prevent clogging due to settling in the pipe during the transport of dredged soil (Kim *et al*., 2015, 2016; Kwon *et al*., 2014; Eunsung *et al*., 2015). Seunghee Kwon *et al*. (2014) also applied this technology to high-pressure concrete conveyance (Choi *et al*., 2014; Su *et al*., 2000). In addition, Su and Lee (1999) have shown an increase in strength of tap water that is mixed with mortar and pozzolans when subjected to this magnetic treatment (Su and Wu, 2003; Su and Lee, 1999).

Therefore, in this study, we aimed to apply this technology to a grouting method by enhancing the motility of water. As water passes through a magnetic field, water molecules are decomposes into small unit clusters thereby lowering its surface tension. In this study, a magnetic field was applied through an EMF (Electromagnetic Field) generator device and a coil. The surface tension and viscosity before and after application of a magnetic field to grout materials were measured and compared. In addition, we developed an instrument to circulate grout material and measure the flow velocity and hydraulic pressure of the grout before and after applying the energy. Furthermore, we investigated the improvement of the fluidity and permeability of the grout material when a magnetic field was applied through an EMF generator device.

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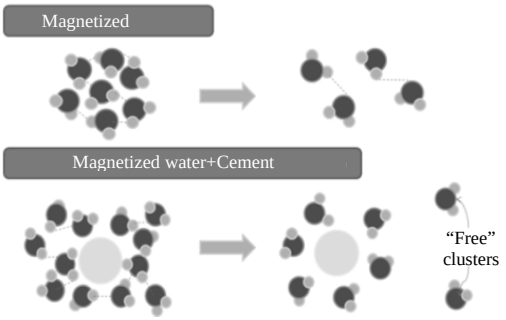

Fig. 1: Effect of magnetic energy field

Litreature review

Theoretical background and laboratory experiments

Theoretical background: As fluid passes through a magnetic field, the clusters of water molecules undergo enhanced motility through exerted external magnetic energy on the clusters and are decomposed into smaller cluster units thereby lowering the surface tension of water. In particular, fluids such as water are polarized and form clusters connected by hydrogen bonding. When a magnetic field is applied, the hydrogen bonding of water is weakened so that, the surface tension is reduced and the molecular structure is decomposed into clusters of smaller units.

Additionally, its viscosity decreases, its reaction area increases and its interfacial reaction efficiency increases so that, the molecular structure changes and the kinetic energy of the fluid is activated (Yu *et al*., 1998; Su *et al*., 2000). Therefore, when this phenomenon is applied to the grouting method it is expected that the reactivity will increase between cement particles and fluidity, as shown in the following figure.

In grouting when cement (Ca_3SiO_5) and water (H_2O) react with each other a hydrated layer is created and a fluidic cement paste is formed. It can be demonstrated in the following procedure (Fig. 1):

$$2Ca_3SiO_5+6H_2O \rightarrow Ca_3SiO_5OH_3+Ca(OH)_2$$

If a magnetic field is applied here water molecules will split into smaller clusters and only the water molecules required for the hydration reaction will be used for cement particles. Therefore, it is possible to expect an improvement in the fluidity of the paste through the generation of surplus water molecules in the cluster form. This results in improved mobility and lower water/cement ratio of hydrates.

MATERIALS AND METHODS

Laboratory experiment: Laboratory experiments were conducted to verify the hypothesized method described in the previous section. The laboratory tests were largely carried out with the aim of examining the effect of a magnetic field on surface tension of water, the viscosity of grout and the fluidity of grout. The detailed specifications of the magnetic field generator can be seen in Table 1. The magnetic energy from the generator was used in conjunction with the coil installed in the pipe (Fig. 2 and Table 2).

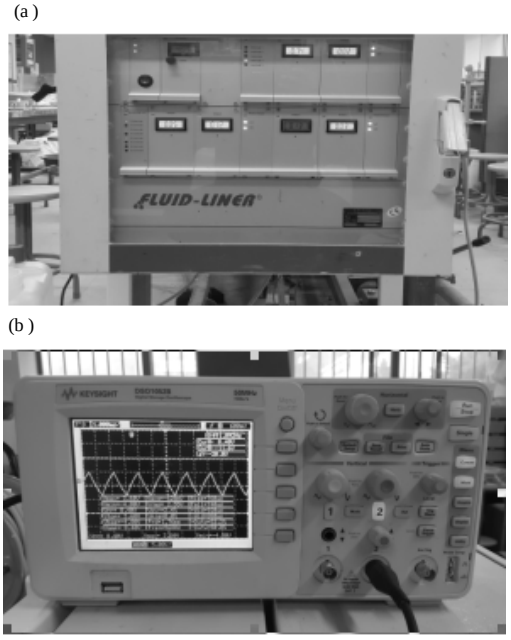

Fig. 2: EMF generator device

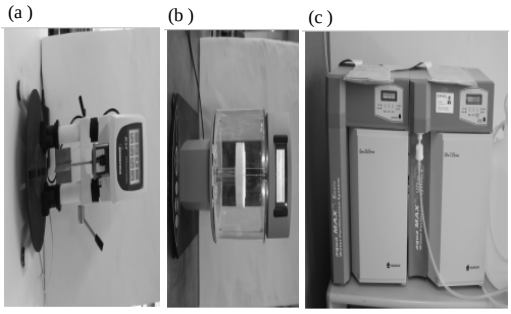

Fig. 3: Experiment devices (viscometer, surface tension meter and distiller)

The surface tension of water induced by the exerted magnetic energy was measured by a surface tensiometer, Attension's Sigma 702 Model. Its viscosity was measured using a Brookfield's RST SST model viscosity meter. All water samples was prepared by using the Ultra 370 Model water distiller of Young In Scientific Co. Ltd., operated at room temperature (23°C). Each instrument used in the experiment is as follows (Fig. 3).

Table.1: EMF generator device specifications and performance

EMF generator Device specification	Specific performance of EMF device
Voltage: 230 V	Power with 6 outputs: 750 VA
Power: 1.5 kVA	Output stages: 3
Main Fuse: 16 A/T type C	CInductors each output: 6
Fuse logic: 1 A/T	pipe diameter: 250 mm per exit
Output data Voltage: 24 V±	Max. pipe diameter: 500 mm = 3 outputs
Current each output: 10 A max	Case sizes: 9U
Number of inductors each pipe: 6	Dimensions (W×H×D)(mm): 600× 497×450
Number of spiels: 25 min	Control unit supply voltage: ±12, +5 V
Each inductor wire diameter: 1.5 mm²	Power no-load operation: 250 mW
Supply Voltage: 230 V	Output current: ±100 mA
Load: 0.1 A	Alarm unit (×2) Voltage: ±12 V

Table.2: Energy intensity at various location in pipe

Time (min)/Section	1	2	3	4	5
1	3.6	1.18	3.50	3.7	0.47
10	5.3	1.38	5.28	3.5	0.48
30	5.1	1.36	5.14	5.4	0.55
60	4.9	1.24	5.80	3.1	0.49

RESULTS AND DISCUSSION

To verify the increase in efficiency it is important to confirm the internal distribution of energy when the magnetic energy is applied to the grout. Therefore, the distribution of the magnetic energy generated in the distilled water located inside the acrylic tube was measured through an energy meter. The inner and outer diameters of the pipe are 390 and 398 mm, respectively and its height is 1, 050 mm. The location of coil and the location of energy distribution measurement are shown in the following (Fig. 4).

The following table summarizes our results of measuring the amplitude (Electro magnetic energy amplitude) of each tube's section by applying a magnetic energy through an electro-magnetic force generator by winding a coil on an acrylic tube. Measured values near the wall surface were on average higher than those of other points. The central part shows a lower value than that of the external point where coil's influence is relatively significant. Particularly, location 5 shows very low amplitude although it is close to the wall. This is due to its being the starting point of the coil.

In addition to the amplitude measurement, the effects of an external magnetic energy on the surface tension of distilled water was examined. The surface tension was measured before and after applying the magnetic field energy. The reduction ratio shown on the lateral side of the graph represents the ratio of the surface tension reduction of distilled water resulting from the application of magnetic energy to the initial surface tension. As

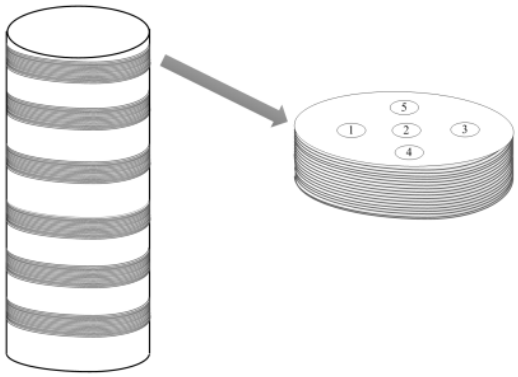

Fig. 4: Amplitude measurement test

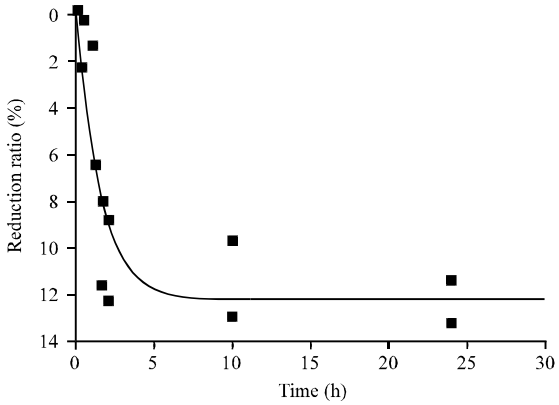

Fig. 5: Surface tension by magnetic energy field

shown in the figure, the surface tension starts to decrease after 1 h and gradually decreases to about 12%. As described in the previous section, water molecule clusters are split by the external magnetic energy.

However, it was difficult to observe the viscosity change of distilled water under the external magnetic energy. It is most likely because the viscosity of distilled water is already too low to measure any minuscule decrease caused by external energy. Next, we measured the change of grout materials in their viscosity (Fig. 5).

Viscosity changes were measured for 50-75 and 100% water/cement ratio before and after the application of a magnetic energy. In 50% water/cement ratio a 19% reduction was observed before (1.8826 mPa.s) and after (1.5344 mPa.s) the magnetic energy application. In 75%, approximately a 12% reduction was observed from 0.4525-0.4003 mPa.s. Lastly, in 100%, approximately an 11% reduction was measured from 0.2574-0.2286 mPa.s. Decreasing rates were measured differently according to

each blending ratio. When the w/c ratio was high, the viscosity decrease was less. Inversely, the viscosity decrease was more when the w/c ratio was relatively low. It is similar to the experimental results of viscosity changes in distilled water. It seems that the effect of magnetic energy does not appear to be significant in the water-rich grout.

It is interesting to note that the decreased viscosity is similar to that of the decreased surface tension. In addition, the decrease in viscosity was observed to be larger in samples with a lower water/cement ratio. This was found to be because the flow characteristics were more influential than in other samples, as the amount of cement particles affecting the fluidization property is larger in this sample. As a result, the sample's fluidity is lower, since, the characteristics of the water inside the body are changed by the external magnetic energy.

The effect of magnetic energy on grout was investigated through a small-scale laboratory experiment. In order to determine its field applicability it is also necessary to consider changes in the characteristics of grout as it flows along the pipe. In this study, a grout transfer system 0was devised to investigate the change of flow characteristics when the grout flowed through the pipe by a pump. The experimental system is as follows.

A 218.7 m long coil was wound around the perimeter of a pipe. Then 50-75 and 100% water-cement ratio grout were circulated for 10 min during the application of magnetic energy through an EMF generator for each experiment. The pressure was then measured with a sensor and a data logger in each section of the pipe.For 50% water-cement ratio, pressure values were 0.601 and 0.505, respectively before and after the magnetic energy through the EMF generator which is about 12.45% reduction. For 75 and 8.29% reduction was observed from 0.137-0.126. For 100 and 4.34% reduction was observed from 0.099-0.095. The values are summarized in the following table and figure. Pressure reduction is a very important aspect of grout because it is related to the grouting pump capacity. In addition, the pressure reduction is due to the decrease of the wall friction resistance and this can be expected to increase grouting efficiency. Although, penetration depth of grout by magnetic energy should have been directly measured, this method is expected to have a positive effect because it is directly related to viscosity and surface tension (Fig. 6-8).

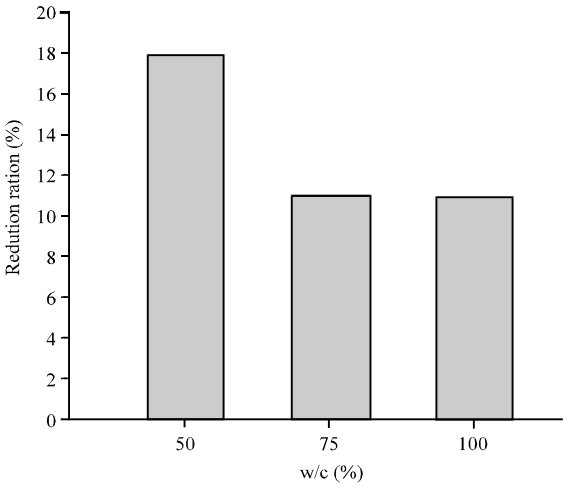

Fig. 6: Viscosity test result

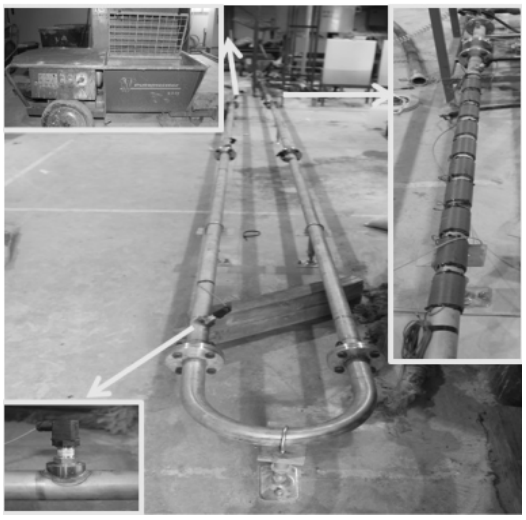

Fig. 7: Pressure measure

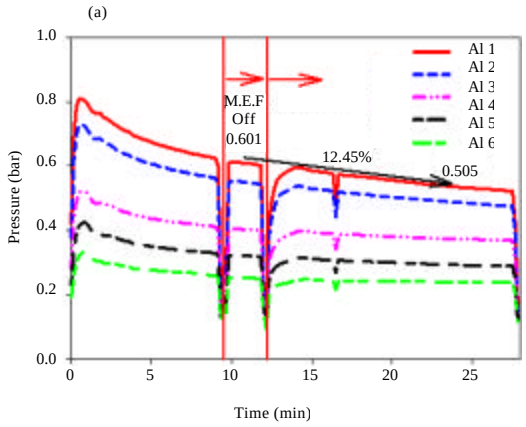

Fig. 8: Continue

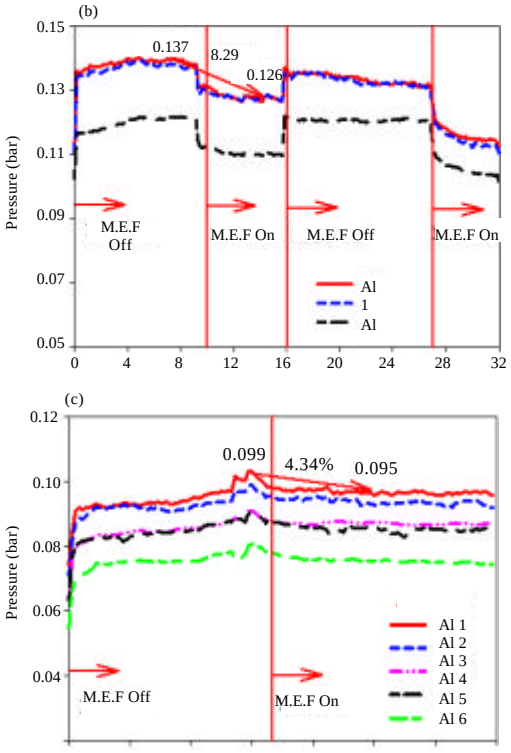

Fig. 8: Distribution of hydraulic pressure according to w/c: a) w/c = 50%; b) w/c = 75% and c) w/c 100%

CONCLUSION

Amplitude, surface tension, viscosity and hydraulic pressure were measured and analyzed by applying a magnetic energy through the EMF generator. All measurements were performed before and after the magnetic energy application.

When measuring the amplitude during the application of a magnetic field energy by winding a coil on an acrylic tube, amplitude values near the wall of the tube were higher and the values near the center measured relatively low. This data suggests that the magnetic energy is distributed densely near the wall surface.

As a result of the magnetic energy, the surface tension was reduced to about 12% and gradually decreased with time before and after the application of the magnetic energy. This implies that clusters of water molecules were split into smaller clusters as a result of the magnetic energy. This increases the reaction area of the water and cement, promotes the hydration reaction and can exhibit effects such as rapid curing, strength enhancement and bleeding deterioration.

The change in viscosity differed according to the mixing ratio of water and cement. However, it was confirmed that viscosity decreased at all blending ratios under magnetic energy influence. The reduction rates of 50-75 and 100% w/c ratio were 19-12 and 11%, respectively. A reason for the difference in reduction rates is that the more the cement particles affecting the fluidization characteristics, the greater the influence of the magnetic energy on the flow characteristics. When the w/c ratio was higher, its viscosity decreased because of insufficient amount of unit cement. Therefore, there is a deviation in measuring viscosity because bleeding occured at the same time as material separation.

The findings concerning pressure, as collected by using the circulation device in the pipe, resulted in 12.45-8.29 and 4.34% reductions with mixing ratios of 50- 75 and 100%, respectively. By applying the magnetic energy to a pipe it is predicted that the flow resistance decreases, the flow rate increases and the fluidity increases. This flow development will reduce the friction and viscous resistance in a pipe and will prevent clogging and sedimentation. It is expected that the grouting efficiency will improved due to the increase of the flow velocity and the decrease of the surface tension and the viscosity.

ACKNOWLEDGEMENTS

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science ICT and Future Planning (No. 2016 R1A2B4013188) .

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