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Development of Filling Material with Fly Ash and Slag as Lubricant in Pipe Jacking Under Acid Sulfate Soils

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Abstract

The pipe jacking method is relatively reasonable among trenchless construction methods.
For the application of this method, the acid sulfate soils have negative impacts on filling materials (one of the cement materials) injected into the tail-void which are over-cutting areas formed to reduce the friction between the pipes and the surrounding soils. In this study, the application of fly ash and slag is discussed to minimize the effect of sulfur acid to filling materials. As the results of the experiments, the addition of fly ash and slag can control the gelling time and prevent the reduction of uniaxial strength of filling materials under the acid sulfate soils. In addition, the filling materials added slag lowered frictional resistance compared to that of fly ash. Filling materials with the lower frictional resistance are preferred to apply for the smooth pipe jacking constructions. Therefore, filling materials added slag would show better performance than that of fly ash under the acid sulfate soils due to its lower frictional resistance.

Keywords: *pipe jacking method, acid sulfate soils, slag, fly ash*

Introduction

In the large cities in Southeast Asian countries, the demand for infrastructure constructions has increased with the growth of the economy and the population (Arc Center of Excellence in Population Ageing Research, 2013). The social infrastructure, however, has to be established under the underground since most of the area is occupied by structures. In Japan, there are social infrastructures including subways, water and sewage systems, and gas pipelines. Two methods are mainly used in Japan to construct the infrastructures under the ground: the open-cut methods and the trenchless construction methods. Although the open-cut method is generally used because of low cost and simplicity, this method causes some social problems such as traffic jams and regulation of traffic in the large cities. On the other hand, trenchless construction methods, such as the shield method and pipe jacking method, allow us to construct the infrastructures under the ground without the problems since they are directly constructed underground. Therefore, trenchless construction methods, especially pipe jacking method, have been widely utilized for the underground construction in Japan (Japan Tunneling Association, 1997).

Pipe jacking is a technique for installing pipelines, ducts, and culverts under the ground. The thrust and the reception pits are constructed, as the pre-construction work. After the construction, the pipelines are installed by transmitting the jacking force with some jacks. The thrust wall is to balance against the jacking force which is changed depending on the pipe size, the strength of the pipeline, the installed length, and the friction resistance (Attandana and Vacharotavan, 1986). Additionally, the tail-void is formed between pipes and surrounding soils in order to smoothly construct underground pipelines by using pipe jacking.

The filling materials are injected into the tail-void as skid during the constructions so as to decrease the friction resistance and to sustain against the overburden pressure as shown in Figure 1. The performance of the filling materials for pipe jacking construction can be summarized as follows:

1. Reducing the frictions between pipes and surrounding soils efficiently
2. Filling through the tail-voids completely
3. Securing the spaces of the tail-voids
4. Sustaining against the overburden pressure

Recently, the pipe jacking method is expected to be used in Southeast Asian countries in order to construct infrastructures underground without the negative effects on the structures on the ground. However, acid sulfate soils which are often observed in the countries may have the negative impacts on cement which are often used in concrete and the filling material (Yamaji et al., 2007). The pH of acid sulfate soils is below 4 (Attandana and Vacharotavan, 1986). The needle-shaped crystals "Ettringite ($6CaO \cdot Al_2O_3 \cdot 3SO_4 \cdot 32H_2O$)" are created by the reaction of sulfur acid in acid sulfate soils and hy-

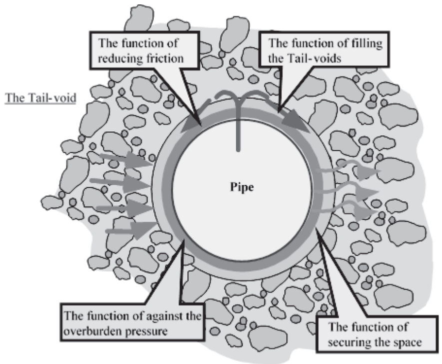


Fig. 1. The functions of filling materials in the tail-void
Rys. 1. Funkcje wypełniania materiałów w pustce końcowej

Tab. 1. Contents of the new filling material
Tab. 1. Skład nowego materiału wypełniającego

Cement	Fly ash	Gypsum	Bentonite	Additive	Fly ash	Slag	Water	Sodium silicate
(g)	(g)	(g)	(g)	(g)	(g)	(g)	(mL)	(mL)
100	140	20	40	8.5	0~20	0~70	830	35

Fig. 2. Rotational friction meter
Rys. 2. Miernik tarcia obrotowego

drate, which is formed by the reaction of clinker (CaO) (main elements of cement) and water, as follows:

$$Ca(OH)_2 + MgSO_4 \rightarrow CaSO_4 \cdot 2H_2O + Mg(OH)_2 \quad [1]$$

$$1.7CaO \cdot SiO_2 \cdot 4H_2O + 1.7MgSO_4 + 1.6H_2O \rightarrow 1.7CaSO_4 \cdot 2H_2O + 1.7Mg(OH)_2 + SiO_2 \cdot 0.5H_2O \quad [2]$$

$$4Mg(OH)_2 + SiO2 \cdot 0.5H_2O \rightarrow 4MgO \cdot SiO_2 \cdot 8.5H_2O \quad [3]$$

$$3CaO \cdot Al_2O3 + 3CaSO_4 \cdot 2H_2O + 26H_2O \rightarrow 6CaO \cdot Al_2O3 \cdot 3SO_4 \cdot 32H_2O \quad [4]$$

$$4CaO \cdot Al_2O3 \cdot SO_4 \cdot 12H_2O + 2CaSO_4 \cdot 2H_2O \rightarrow 6CaO \cdot Al_2O3 \cdot 3SO_4 \cdot 32H_2O \quad [5]$$

Ettringite causes the swelling inside of the filling materials, resulting in the formation of vacant spaces and the decrease of the densities of the materials. This causes the deterioration of the performance of the filling materials. To reduce the effects on the durability of concrete, fly ash and slag are used in some cases. However, fly ash and slag have never been used for the sake of reducing the effect of acid sulfate soils on the filling materials in the construction of underground pipe by pipe jacking methods. From these backgrounds, the application of fly ash and slag is discussed to minimize the effect of sulfur acid to filling materials in this study.

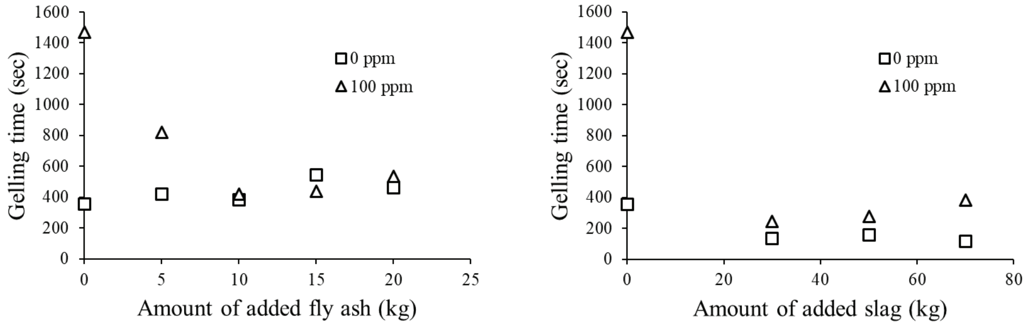
Material and methods

Gelling time measurement

Setting appropriate gelling time is significantly important for pipe jacking construction. Excess of gelling time causes an outflow of the filling material on the ground. On the other hand, the shortage of gelling time blocks the injection of pipes. Therefore, gelling time of new filling materials added fly ash and slag, shown in Table 1, were measured. Fly ash was taken in the coal-fired power plant in Japan. Here, the concentrations of sulfur acid for the water of the new filling material is arranged to 0 ppm and 100 ppm in order to discuss the effects of sulfur acid on its gelling time.

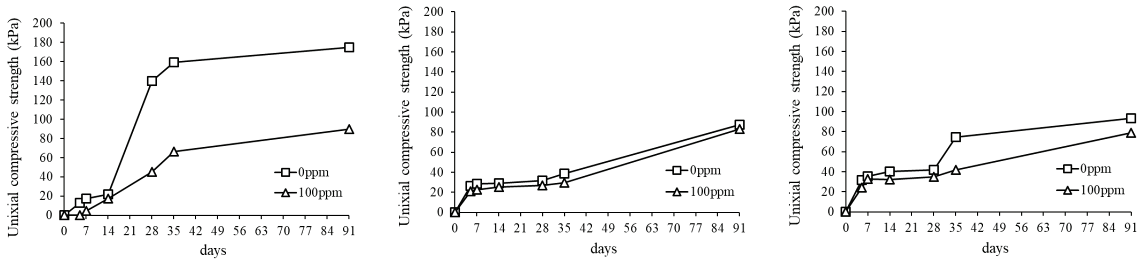
Uniaxial compressive strength (UCS) test

The filling materials injected into the tail-void have to support overburden with enough mechanical strength to keep the space of the tail-void. In order to discuss the impact of sulfur acid on the strength of filling materials, the samples of



(a) Addition of fly ash (b) Addition of slag

Fig. 3. Results of gelling time measurements with and without sulfur acid
Rys. 3. Wyniki pomiarów czasu żelowania z i bez kwasu siarkowego



(a) Without the addition of fly ash and slag (b) Addition of fly ash (c) Addition of slag

Fig. 4. Results of UCS test
Rys. 4. Wyniki testu LUW

the filling materials are immersed in sulfur acid during their curing terms. Curing times were 5, 7, 14, 28, 35, and 91 days. The concentrations of sulfur acid were set 0 ppm and 100 ppm. On a basis of the results of gelling time measurements, one filling material which shows the smallest gap between the gelling times of the filling materials with and without sulfur acid was selected from the filling materials added fly ash and slag, respectively. UCS test was performed to the two filling materials.

Coefficient of friction measurement

The smaller the coefficient of friction of the filling materials is, the less driving force is necessary, leading to reasonable constructions. It is significantly important to understand the coefficient of friction of the filling materials in a sulfuric acid environment. Hence, coefficients of friction of filling materials were measured with the rotational friction meter as shown in Figure 2. In the bottom part of this meter, 2 types of soil were set, respectively: the one was the soil, whose water content was around 10% with water (neutral soil) and another one was the soil, whose water content was around 10% with sulfur acid (acid soil). The pH of acid soil was around 4. At first, the coefficients of friction of neutral and acid soil were measured. After these measurements, the filling materials with fly ash and slag were set on each soil type, respectively in order to understand the performance for the reduction of friction. These measurements were continued for 20 minutes for soils, and 25 minutes for the filling materials.

Results and discussion

Gelling time measurement

The filling materials did not contain fly ash or slag were strongly influenced by sulfur acid (see Figures 3 and 4). Generally, the clinker (CaO) in the filling materials react with water to generate calcium hydroxide ($Ca(OH)_2$) which causes solidification of the filling material (Glasser, 1997). In a sulfuric acid environment, however, the clinker more likely to react with sulfur acid than water to form calcium sulfate ($CaSO_4 \cdot H_2O$). This reaction resulted in the formulation of calcium hydroxide, leading to prevent the solidification. Therefore, conventional filling material showed long gelling time in a sulfur acid environment. On the other hand, the changes of gelling time in a sulfuric acid environment can be minimized by added fly ash and slag. This is because fly ash and slag has alkalinity (Dermatas and Meng, 2003, Manso et al., 2006), meaning that the neutralization occurred before the hydrate reaction. Because of the neutralization, the amount of sulfur acid reduced and the formation of calcium sulfate was prevented, leading to shortening the gelling time. On the basis of these results, the filling materials added 10 g of fly ash and 30 g of slag was selected, respectively, as the sample for UCS test and coefficient of friction measurement.

UCS test

At first, the effect of acid on the strength of the filling material without the addition of fly ash and slag is discussed (Figure 4 (a)). The strength of the filling material does not show potential strength in a sulfuric acid environment. The final strength of the sample cured in 100 ppm sulfur acid is approximately half, compared to the final strength of the samples cured in water. In a sulfuric acid environment, the ettringite reaction is likely to occur, resulting in expansion of

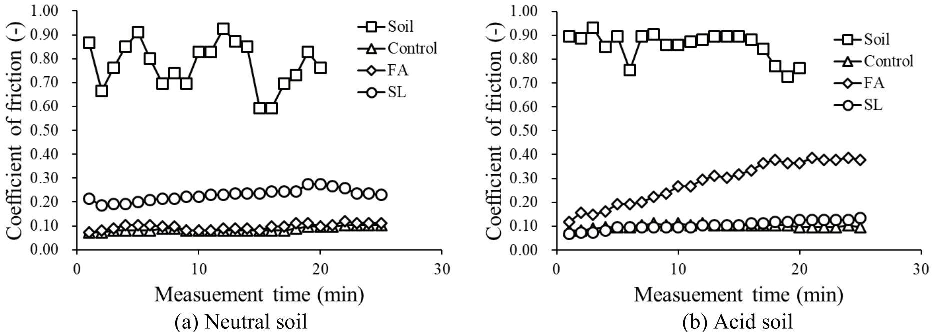


Fig. 5. Results of coefficient of friction measuremets
Rys. 5. Wyniki współczynnika tarcia

the sample. Moreover, the expansion induces generation of new cracks inside the sample and sulfur acid easily ingress into the samples, resulting in deterioration of the strength of filling materials (Grubesa et al., 2016). However, fly ash and slag can control the deterioration of strength because there is less gap between the strength of samples cured in water and sulfur acid (see Figures 4 (b) and (c)). In the case of adding fly ash, silicate oxide (SiO_2) and aluminum oxide (Al_2O_3) in fly ash react with cement in the filling material (pozzolanic reaction). Because of this reaction, durability and water-tightness of the filling material increase, which control the deterioration of the strength (Yamamoto and Kanezu, 2007). On the other hand, slag can increase the density of filling materials, which makes the sample harder (Ueki, 2014). In addition, because of the increase of the density, the pores inside the filling material decrease, leading to block the penetration of sulfur acid into the filling materials and control the deterioration of the strength. Based on these results, it is suggested that fly ash and slag can control deteriorations of strength from sulfur acid.

Coefficient of friction measurement

The coefficient of friction of the filling materials is lower than the soil in both neutral and acid soil (see Figures 5 (a) and (b)). For the filling material without fly ash and slag (Control), the coefficient of friction is decreased dramatically in both neutral and acid soil. In a sulfuric acid environment, however, the coefficient of friction of the filling material with fly ash (FA) gradually increases with time elapsed. Fly ash is generally dominated by small particles and initial strength of fly ash is relatively weak. That is, the filling materials added fly ash does not have enough strength to support the upper part of the rotational friction meter. Because of this, the upper part of the rotational friction meter is likely to contact the soils, resulting in an increase of the coefficient of friction. On the other hand, the coefficient of friction of the filling material with slag (SL) in acid soil is smaller than that of SL in the neutral soil. Slag has a function as the aggregate and maintaining the volume and/or density of the filling materials, leading to support the upper part of the rotational friction meter (Manso et al., 2006). Hence, the upper part of the rotational friction meter hardly contacts with the soils, resulting in controlling of the coefficient of friction. Above all discussions, although both of the new filling materials with the addition of fly ash and slag can be applied to the constructions of pipe jacking in Southeast Asian countries, the addition of slag would show better performance than that of fly ash in terms of coefficient of friction.

Conclusion

From all discussions, the following conclusions can be obtained.

(1) Sulfur acid causes increasing the gelling time and deterioration of strength of the filling materials.

(2) The new filling material added fly ash and slag can control increasing the gelling times caused by sulfur acid. Moreover, the addition of fly ash and slag can also control deterioration from sulfur acid, leading to maintain the strength of the filling materials.

(3) The coefficient of friction of the filling materials added fly ash increases with time elapsed. This result indicates that the filling materials added slag would show better performance than the filling materials added fly ash in Southeast Asian countries

Literatura – References

1. Arc Center of Excellence in Population Ageing Research, Asia in the aging century, [online]. c2013 [cit. 2019-04-25]. Dostupný z WWW: <https://www.neura.edu.au/project/arc-centre-of-excellence-in-population-ageing-research/>.
2. Japan Tunneling Association. Trend of using deep underground and activity report, [online]. C1997 [cit. 2019-04-25]. Dostupný z WWW: < http://www.japan-tunnel.org/>. (Japanese).
3. ATTANANDANA, Tasnee., VACHAROTAYAN, Sorasith. Acid sulfate soils: Their characteristics, Genesis, Amelioration and utilization. Southeast Asian Studies, Vol. 24, No. 2, 1986, p. 155-180, ISSN 0563-8682.
4. YAMAJI, Toru et al. Study on a simple factor on the deterioration of concrete submerged in seawater for long term. Technical note of the port and airport research institute, No. 1150, 2007, ISSN 1346-7840.
5. GLASSER, F P. Fundamental aspects of cement solidification and stabilization. Journal of Hazardous Materials, vol. 52, 1997, p. 151-170, ISSN 0304-3894.
6. DERMATAS, Dimitris and MENG, Xiaoguang. Utilization of fly ash stabilization / solidification of heavy metal contaminated soils. Engineering Geology, Vol. 70, 2003, p. 377-394, ISSN 0013-7952.
7. MANSO, Juan M et al. Durability of concrete made with EAF slag as aggregate. Cement & Concrete Composites, Vol. 28, 2006, p. 528-534, ISSN 0958-9465.
8. GRUBESA, Ivanka Netinger et al. Characteristics and uses of steel slag in building construction. Woodhead Publishing Series in Civil and Structural Engineering, 2016, p. 15-30, ISBN 978-0-08-100368-8.
9. YAMAMOTO, Takeshi and KANAZU, Tsutomu. Experimental explanation of compacting effect on hydration phases and strength development mechanism from pozzolanic reaction of fly ash. Journal of JSCE, Vol. 63, No. 1, 2007, p. 52-65, ISNN 1880-6066.
10. UEKI, Yasutomo. History and utilization of portland blast furnace slag cement. Nippon Steel & Sumitomo Metal Technical Reports, No. 399, 2014, p. 110-114, ISNN 0916-7609.

Materiał wypełniający z popiołem lotnym i żużlem jako środkiem smarnym w przeciskaniu rur pod kwaśnymi gruntami siarczanowymi

Metoda przeciskania rur jest zaliczana do metod budowy bezwykopowej. W przypadku zastosowania tej metody kwaśne gleby siarczanowe mają negatywny wpływ na materiały wypełniające (jeden z materiałów cementowych) wstrzykiwane w pustkę końcową, które są obszarami utworzonymi w celu zmniejszenia tarcia między rurami a otaczającymi glebami. W artykule omówiono zastosowanie popiołu lotnego i żużla w celu zminimalizowania wpływu kwasu siarkowego na materiały wypełniające. W wyniku eksperymentów stwierdzono, że dodanie popiołu lotnego i żużla pozwala na kontrolowanie czasu żelowania i zapobiega zmniejszeniu jednoosiowej wytrzymałości materiałów wypełniających. Ponadto dodany materiał wypełniający obniżył opór tarcia w porównaniu z popiołem lotnym. W przypadku gładkich konstrukcji rurowych zaleca się stosowanie materiałów wypełniających o niższym oporze tarcia. Dlatego dodany żużel z materiałów wypełniających wykazywałby lepszą wydajność niż popioły lotne ze względu na niższy opór tarcia.

Słowa kluczowe: *metoda przeciskania rur, kwaśne gleby siarczanowe, żużel, popioły lotne*