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Magnesium chloride and sulfate attacks on gravel-sand-cement-inorganic binder mixture

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HIGHLIGHTS

- Chemical attack on the mixture combined with inorganic binder are investigated.
- Inorganic binder enhances the durability and reduces strength degradation.
- Correlations between strength and geophysical properties are obtained.

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ABSTRACT

Investigation on the degradation of improved ground is crucial for predicting its life span and performance under unfavorable conditions. In this study, effects of magnesium chloride ($MgCl_2$) and magnesium sulfate ($MgSO_4$) attacks on gravel-sand-cement-inorganic binder mixtures were investigated. Electrical resistivity, free-free resonant column (FFRC) and uniaxial compression tests were performed at different exposure periods, and results showed that saline solutions exert considerable effects on the geophysical parameters of the mixture. As the samples were exposed to chemical attacks, the electrical resistivity and damping ratio increased, while the longitudinal wave velocity and UCS decreased. Especially, the results at 28 days showed that mixtures without inorganic binder lost approximately 40% of its initial strength in $MgCl_2$ and 12% in $MgSO_4$, while samples with inorganic binder (IBS) only lost about 30% and 8% in $MgCl_2$ and $MgSO_4$ respectively. Thus, it is expected that increasing the inorganic binder content in the mixture can enhance the performance of the grout and reduce strength degradation induced by chemical attacks.

1. Introduction

Cement-based materials are widely used for improving the ground in applications such as grouting, building and plant foundations, road bed and highway subbase, and repairing cracks and failures on concrete and masonry structures [1–4]. Grout is a typical cement-based material commonly used in geotechnical fields, and it is generally constructed by mixing soil particles with cement and, sometimes, by adding additional binding materials. Grout is considered an important material for designing tunnel supports system such as lining backfilling, rockbolt bonding strength, protective umbrella for cohesionless soils, and curtain grouting in dam foundations and dikes [5,6–8].

However, grout can be subject to deterioration when it is exposed to corrosive chemicals such as chloride and sulfate solutions. In particular, most of the coastal areas where large-scale civil engineering works are expected are composed of soft ground. Thus in such areas, the durability of materials is drastically reduced due to the action of salt, organic matter, and various ions of marine clayey soils. Beside sea water, grout can also be exposed to saline solutions when it is installed in contaminated ground with industrial wastewater or in deep foundation where groundwater is present [9]. Therefore, the influence of the adjoining materials on the grout should be significantly considered in order to secure grout performance.

Several scholars have investigated the effects of salt solutions on the performance of cement-based materials [10–12]. The authors found that chemicals affect the properties of cement-based materials because they can alter their physical and chemical characteristics when reacting with cement during the hydration process. Yildirim and Sumer [9] noticed that chloride solutions are more dangerous to cement-based materials than sulfate solutions. Indeed, chloride ions react with cement and break down

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the calcium silica hydrate (C-S-H) and crystal salt in the mixture. Nonetheless, when cement-based materials are subjected to sulfate attack, ions exchange between the sulfate solutions and C-S-H leads to the formation of non-cementitious materials that soften the materials [10,13]. Although the previous researches were extensively conducted on cement-based grouts, only a limited work has been reported focused on geophysical parameters such as electrical resistivity, elastic wave velocity and attenuation under effects of chemical attacks for grout combined with inorganic binder. These parameters are useful for non-destructive evaluation of the grout in the field, and, can also be correlated to geotechnical characteristics of the mixtures [14].

Inorganic binder nowadays is considered as one of the effective alternative binders for the improvement of the performance of cement-based mixtures, especially when the grout is exposed to chemical attacks. Inorganic binders are able to supply alternative amounts of C-S-H, thereby strengthening the material and produce strongly alkaline materials ($Ca(OH)_2$) during the hydration of cement [1,15]. Comrie [16] claimed that inorganic binders are the most suitable materials to resist chemicals, and are particularly useful in construction in saline and aqueous environments since they have specific properties such as high surface smoothness, precise mobility, and quick hardening ability. Numerous previous researches investigated effects of chemical attacks on the grout mixed with inorganic materials [13,15]. However, only a few studies have considered the effects of magnesium chloride ($MgCl_2$) and magnesium sulfate ($MgSO_4$) on geophysical characteristics of grout mixed with inorganic binder.

Therefore, the primary objective of this paper is to investigate the effects of $MgCl_2$ and $MgSO_4$ attacks on the geophysical characteristics of the grout, and analyze the influence of inorganic binder in the mixture through a comparative study of mixture with inorganic binder (IBS) with mixtures without inorganic binder (CMS).

2. Materials

2.1. Binding materials

Portland cement Type I and inorganic binders were used as binding materials in this study. The inorganic binder constituents were made of calcium oxide (CaO), aluminium oxide (Al_2O_3), and calcium sulfate ($CaSO_4$) reacting in a saturated solution. Fig. 1 presents the syrup binder (SB) and fine powder binder (FPB) used in this study. Syrup binder generates a large amount of strong alkaline materials during the cement hydration process. When two different forms of binder are mixed together, calcium silicate hydrate (C-S-H) gel is produced. The chemical composition and physical properties of cement and inorganic binders used in this study are described in Table 1 [14,17]. In the presence of sulfur trioxide (SO_3), calcium aluminate ($CaAl_2O_4$) reacts particularly with water in the mixture to produce various aluminates such as monosulfate ($3CaO{\cdot}Al_2O{\cdot}3CaSO_4{\cdot}12H_2O$) and calcium silicate hydrate (C-S-H); the latter plays a significant role in enhancing material solidification and sustaining its strength [15].

Table 1
Chemical and physical properties of cement and inorganic binder.

	Cement (%)	Inorganic binder (%)	ASTM C 150 Maximum requirement for cement I (%)
Silica (SiO_2)	20.70	2.20	–
Alumina (Al_2O_3)	4.20	23.90	–
Iron oxide (Fe_2O_3)	3.10	0.70	–
Calcium oxide (CaO)	63.30	42.60	–
Magnesium oxide (MgO)	3.90	0.20	–
Sulfur trioxide (SO_3)	2.30	28.30	6.00
Ignition loss	1.90	0.60	3.00
Insoluble residue	0.30	0.80	0.75
Specific gravity	3.10	2.96	–
Fineness (cm^2/g)	3200	5500	–

2.2. Gravel-sand mixture

Sieve analysis was performed in a laboratory to characterize the physical properties of gravel and sand particles. As illustrated in the grain size distribution chart (Fig. 2), the soil particles used for this experiment were coarse-grained sand with poor particle size distribution mixed with gravel (SP) [18]. Properties of the gravel-sand mixture are as follows: specific gravity is 2.86 and coefficient of gradation is 0.18.

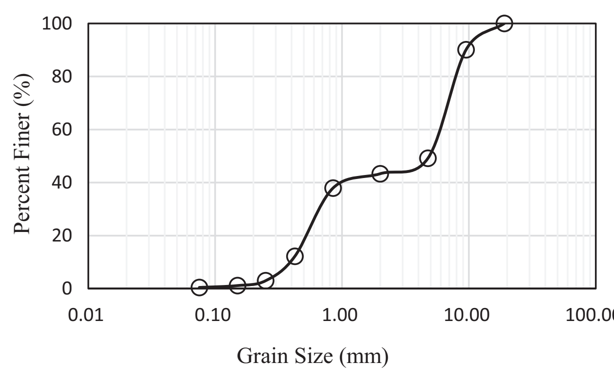

Fig. 2. Grain size distribution of gravel-sand mixture.

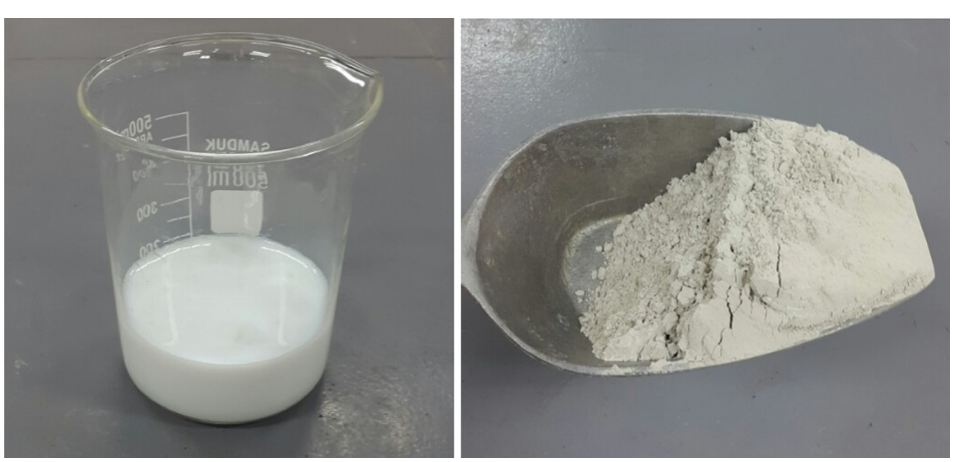

Fig. 1. Syrup and powder inorganic binders.