Effect of aggressive solution and soaking on shear strength of marl clay stabilized by co-polymer of vinyl acetate and acrylic esters

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ABSTRACT
In this research, an experimental study was carried out to investigate the effect of co-polymer of Vinyl Acetate and Acrylic Esters (VAAE) on the shear strength of Marl clay from southern zones of Shahrood, Iran. Furthermore, the effect of soaking, temperature and sodium chloride solution (NaCl) as an aggressive solution on the shear strength of treated specimens are investigated. The engineering characteristic of clay would be affected when the level of groundwater changes in wet seasons or after long rainfall. Therefore, to study the effect of soaking on polymer treated samples, the specimens were soaked both partially and fully in water prior to the unconfined compressive test. Also, the effect of high temperature on the shear strength of specimens was investigated by applying high temperature (40 ℃ and 70 ℃) conditions prior to the unconfined compressive strength test. To study the effect of the salt solution, specimens were prepared with different concentrations of NaCl solution. The study concludes that the stabilization of marl clay with co-polymer of Vinyl Acetate and Acrylic Esters (VAAE) improved the shear strength of the soil. Furthermore, higher temperatures and soaking positively affect the shear strength of polymer treated specimens.
Keywords: Shear strength, Marl clay, Unconfined compressive strength, Stabilization, Aqueous polymer

RÉSUMÉ
Dans cette recherche, une étude expérimentale a été effectuée pour enquêter sur l'effet du Copolymère acétate de vinyle et Esters acryliques (VAAE) sur résistance au cisaillement l'argile de marne des zones sud de Shahrood, Iran. En outre, les effets du trempage, la température et du chlorure de sodium (NaCl) comme solution agressive à la résistance au cisaillement des échantillons traites a été étudiée. Les caractéristiques techniques de l'argile seraient affectées lorsque le niveau des eaux souterraines change en saison humide ou après des longues pluies. Par conséquent, pour étudier l'effet du trempage avec un polymère, les échantillons sont trempés à la fois partiellement et complètement dans l'eau avant le test de la compression non confinée. Aussi l'effet de la température élevée sur la résistance au cisaillement des échantillons ont été étudiés en appliquant une haute température (40°C et 70°C) conditions préalables au test de la résistance à la compression non confinée. Pour étudier l'effet de la solution saline, des échantillons ont été préparés avec différents concentration de solution de NaCl. L'étude conclut que la stabilisation de l'argile de marne avec le Copolymère acétate de vinyle et Esters acryliques (VAAE) améliore la résistance au cisaillement du sol. De plus, une température plus élevée et un trempage ont un effet positif sur la résistance au cisaillement des échantillons traités au polymère.

MOTS CLES : résistance au cisaillement, Argile de marne, résistance à la compression non confinée, Stabilisation, polymères aqueux.

1 INTRODUCTION

Undesirable soil characteristics including low bearing capacity, high moisture absorbency, high shrinkage, and swell potential are ascribed to the fines present in the material (Santoni et al. 2002). Soil stabilization refers to the process of changing soil properties in order to improve strength and durability. The techniques that have been suggested for soil stabilization can be placed in two groups of mechanical stabilization and chemical stabilization methods. Chemical stabilization can be performed with traditional stabilizers or non-traditional stabilizers. The effect of traditional stabilizers on soil's behavior have been well documented over the years (Miller and Azad 2000, Brooks 2009, Phummiphan et al. 2018, Corrêa-Silva et al. 2018). For example, traditional calcium-based mixtures such as cement and lime have a long history of use in soil stabilization applications (Barbhuiya et al. 2009, Abo-El-Enein et al. 2013, James and Pandian 2016). In stabilization of soil with lime, calcium cations supplied by hydrated lime replace the cations normally present on the surface of the clay mineral, promoted by the high pH environment of the lime-water system. Thus, the clay surface mineralogy is altered, producing plasticity and swelling reduction, reduction in moisture holding capacity (drying), Improved stability and ability to construct a solid working platform. However, traditional techniques often require time-consuming cure processing and also large quantities of the additive for significant improvement (Santoni et al. 2002). Furthermore, lime and cement have the potential to conduct the adverse chemical reaction in sulfated soils (Little et al. 2009, Gadouri et al. 2017). Therefore, the use of polymers as non-traditional soil-stabilizing additives has expanded significantly in the past decade (Orts 2007, Naeini et al. 2012, Latifi et al. 2016). The selection basis of polymer stabilizer for soils lies on the ability of the polymer to form a coating film on the soil grains. On the other hand, polymers soluble in water can be transported in runoff water. Therefore, stable dispersions in water, called latex, seem to be appropriate. Latexes are composed of water, monomers, initiators, and surfactants. Colloids, pH regulators, plasticizers and solvents are also commonly used in these emulsions to optimize the final efficiency. Azzam (2012) used 15 wt% polypropylene homopolymer mechanically mixed in xylene solution for 24 hrs to stabilize clay soils and observed a 16-60% reduction in free swelling with different polymer contents. Gopal et al. (1983) optimized the depth of stabilization required for construction of roads in sandy areas studying the performance of different contents of ureaformaldehyde resin for stabilization of dune sand. Ajayi et al. (1991) performed the epoxy-based treatment as a non-traditional stabilization method on a fine poorly graded soil type in order to minimize soil erosion of clay-silt pavement systems. Results showed that the addition of 4% stabilizer composed of bisphenol A/epichlorohydrin hybrid resin plus a polyamide hardener could significantly increase the bearing ratio. They also found that moisture content and temperature are significant variables influencing soil strength as well as additive level. Orts et al. (2007) suggested a formulation of polyacrylamide/aluminum chlorohydrate/cross-linked polyacrylic acid at a ratio of (6:1:1) minimizing dust clouds during helicopter operation. Lately, anionic polyacrylamide, polyvinyl acetate, and vinyl acrylic copolymers are also reported to be used as soil conditioners for erosion control, soil stabilization and non-desertification purposes (Rabiee et al. 2013, Vitale 2013, Ates 2013, Rodriguez et al. 2018, Law et al. 2018). Rabiee et al. (2013) observed the positive effect of higher molecular weights of anionic polyacrylamides containing cationic metal ions i.e. potassium persulfate, calcium chloride, and sodium carbonate on the soil strength.

In this research work, vinyl acetate acrylic ester (VAAE) is selected to stabilize Marl soil characteristics, as this co-polymer is stable in the soil after curing and is unlikely to be involved to terrestrial organisms or be transported in runoff water (Steevens et al. 2007). To the best of the author's knowledge no reports are available on the contribution of VAAE into the Marl soil stabilizers. The main aim of this article is to study the effect of vinyl acetate/acrylic ester composition on the stabilization process and shear strength of Marl clay. Furthermore, to gain a better understanding on the effect of environmental climate change on the behavior of stabilized clay, the effect of soaking, temperature and sodium chloride solution (NaCl) as an aggressive solution on shear strength were investigated. Attempts have been made to develop a multidisciplinary approach gathering both chemical and geotechnical findings.

2 MATERIALS AND METHODS

2.1 Materials

2.1.1 Soil

The Marl clay was used in this study was obtained from the southern zones of Shahrood, Iran. The grain size distribution of the Marl clay is presented in Figure 1.

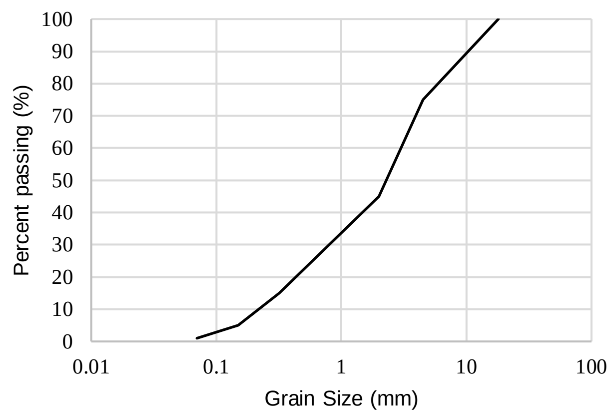

Fig 1. Grain size distribution

The specific gravity of Marl clay was obtained based on ASTM D854-14 (2014). Standard proctor compaction test was carried out for determining the optimum water content based on ASTM D698-12e2 (2012). For assessment on plasticity behavior of Marl clay, the Atterberg Limit test was carried out based on ASTM D4318-17e1 (2017). the results indicate that the type of Marl clay in this study was CL based on the Unified Soil Classification System (ASTM D2487-17. 2017). The physical properties of Marl clay are presented in Table 1.

Table 1. Physical properties of Marl clay

property	Marl clay
Specific gravity (%	3.17
Optimum water content (%)	14
Plastic limit (%)	17
Liquid limit (%)	38
Plasticity index (%)	21
Soil classification	CL

2.1.2 Polymer

Emulsions selected in this study to be utilized as soil stabilizers is a non-plasticized aqueous dispersion based on vinyl acetate and acrylic esters (VAAE). Physicochemical properties of VAAE emulsion supplied by Resinfam Company, **Iran**, are listed in Table 2.

Table 2. Physicochemical properties of VAAE

Property	VAAE
Physical state	Liquid
Color	Milk white
Viscosity (cP)	3000±1000
Density (gr/cm^3)	1.1
PH	4.5±0.5
Solid content (%)	46±1
Minimum film formation temperature (℃)	-2

2.2 Methods

All specimens were prepared based on ASTM D698-12e2 (2012) with different concentration of VAAE solution and then unconfined compressive strength test was carried out to measure the effect of different condition on shear strength behavior of treated specimens based on ASTM D2166 (2016).

2.2.1 Partially soaking test

To examine the soil's strength under rainfall condition, shear strength of un-treated and polymer-treated specimens were measured under partially soaking conditions. In this test the Marl clay was mixed with different concentrations of VAAE (1.5%, 2.5%, 4%, 6.5%, 9%, 11.5%, 14%). The specimens were prepared according to the ASTM D698-12e2 (2012) standard test method. The specimens were then put in a container which was filled with water up to a quarter of the specimen's diameter. The specimens were placed in the container for 3 minutes in order to soak to half of their volume (Figure 2). Afterward, the specimens were put on a filter paper to dry. After drainage, the unconfined compressive test was performed.

Fig 2. Partially soaking test

2.2.2 Fully soaking test

In this test the specimens were mixed with different concentrations of VAAE (1.5%, 2.5%, 4%, 6.5%, 9%, 11.5%, 14%). The specimens were prepared according to the ASTM D2166 (2016) standard test method. The specimens were put in a container full of water for 3 minutes until the whole surface of the specimen becomes wet (Figure 3). The specimens were then placed on a dry surface for 5 minutes to drain. Afterward, the unconfined compressive test was performed.

Fig 2. Fully soaking test

2.2.3 Aggressive solution test

For this test the optimum percentage of VAAE by dry mass of clay obtained by standard proctor compaction test (Figure 3). The results of the standard proctor test show that after 8% of VAAE the change in dry density of specimens slightly increased. Therefore, all the specimens were mixed with 8% VAAE by dry mass of clay. Four different concentrations of NaCl (1%, 3%, 7%, and 10%) were used to study on the effect of the aggressive solution. The specimens were prepared according to ASTM D2166 (2016) prior to the unconfined compressive test.

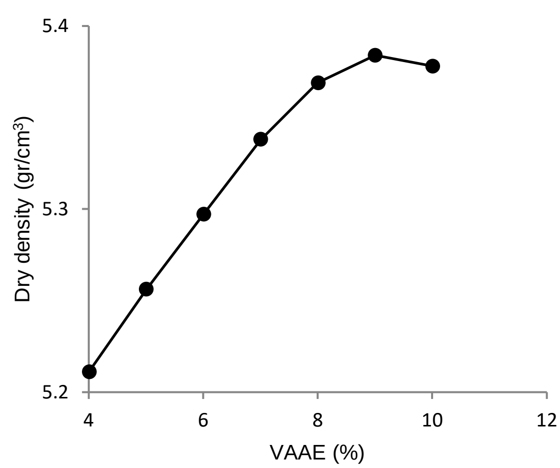

Fig 3. Optimum VAAE percentage

2.2.4 High temperature test

To study the effect of temperature on shear strength behavior of treated specimens, the optimum percentage of VAAE was selected (8%) and the specimens were placed in the oven at two different temperatures (40 ℃ and 70 ℃) prior to unconfined compressive strength.

3 RESULTS AND DISCUSSION

3.1 Partially soaking test

The results of unconfined compressive strength tests for different concentrations of VAAE under partially and fully soaked conditions are presented in Figure 4.

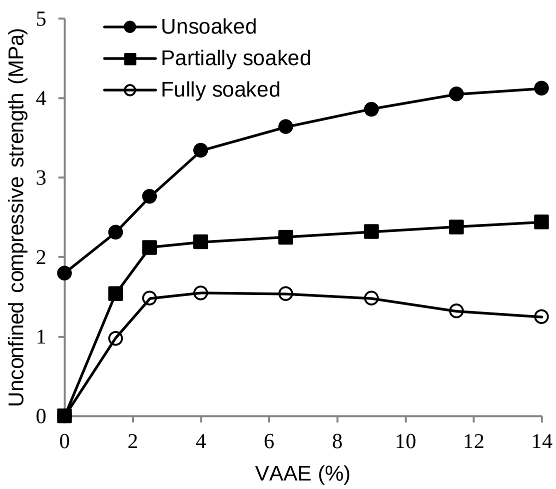

Fig 4. Unconfined compressive strength under the partially soaked condition

The results show that shear strength reduces when the samples are in partially soaked condition (About 40.78% in 14% of VAAE). By putting the specimens in the partially soaked condition the clay particles tend to disperse in water Hence, untreated specimens did collapse. However, in co-polymer treated specimens the chains of polymer around the clay particles provide support for macropores and limit the movement of the particles. Therefore, the addition of co-polymer prevents the soil from collapsing. The result indicates that by the addition of VAAE to the solution, the unconfined compressive strength of specimens increased significantly. Also, it can be observed that after 2.5% of VAAE the increment in unconfined compressive strength becomes slight.

3.2 Fully soaking test

Polymer latex suspended in the emulsion by surfactants coat soil particles and physical bonds are formed when water carrier evaporates. Hydrodynamic pressure through evaporation causes the polymer chains to coalesce to form a continuous film of polymer around the aggregates conglomerating soil particles into a solidified soil–polymer matrix (Welling 2012). From Figure 5, it can be seen that at a fully soaking condition, the unconfined compressive strength of the treated specimens was dropped about 69.66% (In 14% VAAE).

Comparison of the results from partially and fully soaked tests indicate that there is a reduction in unconfined compressive strength in fully soaked condition compared to partially soaked condition. This reduction is due to a higher tendency of clay particles to disperse in a fully soaking condition. Although, the web of VAAE provides support around the clay particles and macro pores however, further interactions between water molecules and clay particles reduce the unconfined compressive strength.

3.3 Aggressive solution test

The results of unconfined compressive strength tests for different concentrations of NaCl are illustrated in Figure 5.

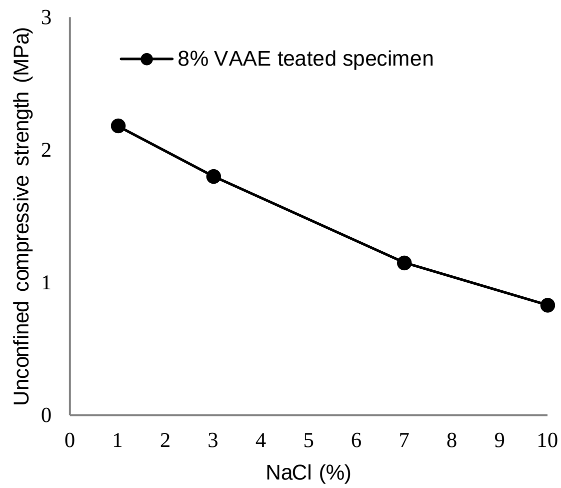

Fig 5. Effect of NaCl solution on unconfined compressive strength of 8% VAAE treated specimen

The results indicate that the increase in salt concentration reduces the shear strength of the stabilized soil. The addition of 10% NaCl reduces the shear strength of the polymer-treated soil by 77%. The negative effect of NaCl on the shear strength of polymer-stabilized clay can be attributed to the dispersive nature of NaCl. Salt addition affects the nature of overall charges in the polyelectrolyte solution. The addition of salt increases the ions and counter ions concentration which will increase the electrostatic repulsions between reacting chains. This result is in agreement with the findings of Einarson and Berh (1992).

3.4 High temperature test

The effect of high temperature on shear strength properties of the treated specimens is presented in Figure 6.

The results show that by increasing the temperature, the rate of chain formation of polymer in mixture increased. The treated specimens after drying for 24 hours' oven at 40℃ was gained 52% of their unconfined compressive strength while in room temperature was gained after over 28 days. It should be mentioned that the specimens gained 87% of their unconfined compressive strength when the temperature raised up to 70℃.

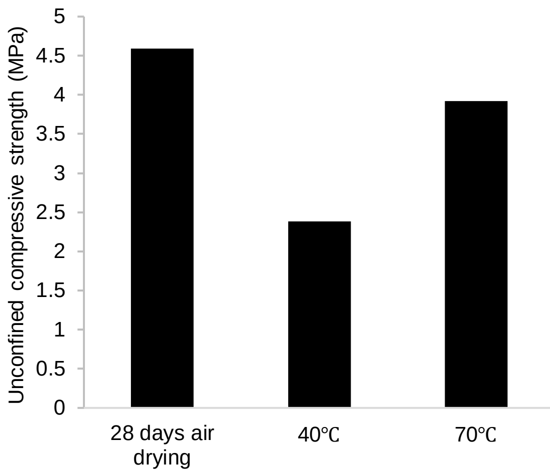

Fig 6. Effect of high temperature on unconfined compressive strength of 8% VAAE treated specimen

4 CONCLUSION

The results of this study indicate that the addition of the VAAE concentration improves the unconfined compressive strength of stabilized Marl clay specimens. The formation of polymer chains around the clay particles binds the particles together, and make a significant improvement on unconfined compressive strength of specimens under partially and fully soaking conditions. Also, while the untreated specimens collapsed under partially and fully soaking condition, after stabilizing the soil with co-polymer the specimens remained stable and it was observed that the unconfined compressive strength changed slightly due to the increment of VAAE concentration. After introducing the NaCl solution as an aggressive solution to the mixture, the unconfined compressive strength of the specimens dropped significantly (about 77% in 10% NaCl concentration). Therefore, it can be concluded that the process of polymerization could not be completed and the presence of salt has a negative effect on the shear strength of the VAAE stabilized the soil. The results show that applying high temperature during the drying process has a significant effect on accelerating the chain formation process of VAAE. Which considered an advantage when VAAE in hot climates.

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