Dispersion Potential of a Clay Soil Stabilized by Alum. A Case Study

H.R. Jafari, M. Hassanlourad, M.R. Hassanlou

Abstract. In this paper modification potential of dispersive clay by white natural alum is evaluated. The studied clay is taken from basin of a constructing dam, called "Mirzakhanloo", located in Zanjan province, northwest of Iran. Dispersion potential of soil and its modifiability were evaluated using pinhole, single and double hydrometric, chemistry and standard compaction tests. The influence of alum on the Atterberg limits of soil was also studied. Tests results indicated that adding the alum and curing time up to 28 days, under hydraulic gradients up to 26.84, decreases the dispersivity of the modified soil. Increasing the alum content increases the plasticity limit. Liquid limit, plasticity index and pH of the soil were increased by adding the alum up to 0.6%, and then decreased. Both the plasticity and liquid limits were decreased by curing time, however the plasticity index variations were limited. Electrical conductivity (EC), and Sodium absorption ratio (SAR) of the soil were increased and total suspended solids (TSS) in the leached water were decreased by increasing the alum content and curing time. Generally, addition of 3% alum stabilized the used soil knowing that maximum dry density and optimum moisture content were obtained at 1% of alum.

Keywords: dispersive clay, stabilization, alum, pinhole test, chemical test, hydrometric test.

1. Introduction

Ions type of clay soils is one of the important issues which must be always considered when encountered as barrow resources of earth dams and so on. Past experiences indicated that ignoring this for implementing the water structures made many problems and caused structural damages. Erosion and changes in the structure, physical and mechanical properties of the soil are the most important reported problems of these soils (Asgari & Fakher1994).
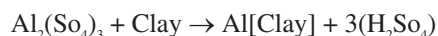
Dispersive soils are related to clays particles that can be easily washed by waters with low salt contents. Such clays usually contain high content of sodium ions in their absorptive ions. Dispersion is a progressive phenomenon beginning from a point with high water concentration which gradually develops. Cracks from condensation, differential settlements and hydraulic gradient could result in dispersion. Dispersive phenomena knowledge is very important in the projects involving earth dams and water canals design and construction. Dispersive soils are abundant in different climates and regions through the world, such as Australia, Brazil, Iran and USA (Vakili et. al, 2009a, b).

The dispersive soils may not be recognized by regular soil classification tests. Therefore it is usually recommended to simultaneously use four tests to recognize them, including Pinhole, Kramb, chemical and double hydrometric tests (Ryker, 1977 and Sherard & Decher, 1977).
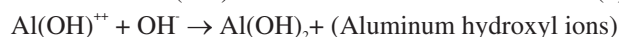
Dispersive phenomenon has usually a physical- chemical nature influenced by the type of soil's minerals and chemical properties of pore water. When a dispersive soil is exposed to the seepage, the clay particles are likely to separate from each other and be suspended. This results in the formation of piping phenomena in the earth dams together with erosion and demolition of roads and water canals as well as destruction of structure's foundation (Ouhadi & Goodarzi, 2006 and Sherard *et al.*, 1972). In the past, it was being severely stressed on not increasingly usage of such type of soils, but today it has been paid more attention to improve and use these soils. The most important factors influencing the improvement ability include: type and concentration of pore water ions, chemical properties of runoff and seepage water, cracking, and clay particles (Asgari & Fakher, 1994).

In this study the white natural alum, $Al_2(SO_4)_3.18H_2O$, was used for stabilizing a dispersive clay soil, in which, sodium cation (Na^+) is replaced with aluminum cation (Al^{3+}). In such replacement, the soil structure is changed from dispersive to flocculated state, reducing the repulsion force between the particles and then the dispersive potential of soils (Heidarian, 1993).

$$Al_2(So_4)_3 + Clay \rightarrow Al[Clay] + 3(H_2So_4)$$
and
$$Al^3 + OH^- \rightarrow Al(OH)^{++} \qquad (1)$$
$$Al(OH)^{++} + OH^- \rightarrow Al(OH)_2+ \text{(Aluminum hydroxyl ions)}$$

The effects of adding different percentages of aluminum sulfate and curing times on a dispersive soil were evaluated using double hydrometric, pinhole and chemical tests. Atterberg limits test was also used for studying the in-

Hamid Reza Jafari, MSc. in Soil Mechanics,Young Researchers Club, Zanjan Branch, Islamic Azad University, Zanjan, Iran. e-mail: hamidrezajafari1@yahoo.com.
Mahmoud Hassanlourad, PhD. Assisstant Prof. of Soil Mechanics, Imam
Khomeini International University, Qazvin, Iran. e-mail: hassanlou@eng.ikiu.ac.ir.
Mohammad Reza Hassanlou, PhD. Assisstant Prof. of Soil Mechanics, Zanjan Branch, Islamic Azad University, Zanjan, Iran. e-mail: Mhasanlo@yahoo.com.

Soils and Rocks, São Paulo, 36(2): 221-228, May-August, 2013.

221

fluence of alum on the plasticity limits. Standard compaction test was used for studying the effect of alum on the maximum dry unit weight and optimum moisture content.

2. Material and Methods

The soil used in this study was obtained from a site of dispersive clays present in the basin of an earth dam called Mirzakhanloo 2, Gohar, located in in Zanjan province, North West of Iran.

Dispersion specifications and chemical properties of the used soil are summarized in Tables 1 and 2, respectively. Based on these Tables it is concluded that the used soil is classified in the category of wholly dispersive soils with highly vulnerable to erosion. Particle size distribution using single and double hydrometric tests is shown in Fig. 1. The used soil was classified by two soil classification systems of Unified and ASHTO as CH and A-7-5, respectively. Also, specific gravity of soil particle was 2.76 (Table 3).

2.1. Sample preparation and test programming

First compaction test was performed on the soil. For stabilization process, all samples were prepared at optimum moisture content and then cured. The additive content of alum included 0.6, 1, 3, 5 and 10 percent of soil dry weight. Prepared samples were cured up to 1, 7, 14 and 28 days. Pinhole, chemical and hydrometric tests were done for studying the soil dispersion and its modification process. All tests were conducted according to ASTM standards.

2.1.1. Pinhole tests

Pinhole test was introduced by (Sherard *et al.*, 1972). In this test, which is also called Sherard Test, the dispersion
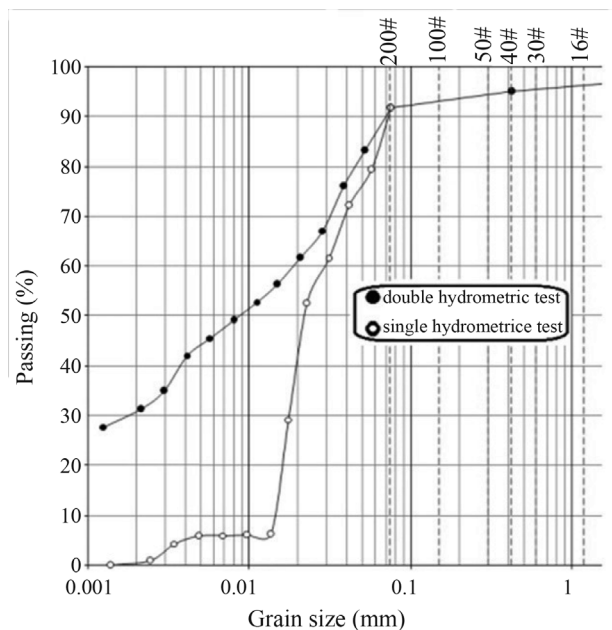

Figure 1 - Particle size distribution based on the single and double hydrometric test.

rate of fine-grained soils is measured by directly passing the water from a hole (with 1 mm in diameter) made in the soil sample. The leached water from dispersive soils sample is muddy containing colloids; nevertheless, in non-dispersive sample, it is clear. In this research, pinhole tests conducted on samples with length of 38 under the water heads of 50, 180, 380 and 1020 mm (hydraulic gradient of 1.32, 4.73, 10 and 26.84) by three methods of A, B and C (ASTM D4647). Figure 2 shows a picture of the pinhole test. The results are shown as water discharge, clarity of the

Table 1 - Dispersive properties of the used clay.

Classification based on pinhole test	Classification based on double hydrometric test	Dispersion percent in double hydrometric test
Wholly dispersive D1	Wholly dispersive	59.20

Table 2 - Chemical properties of the used soil.

$(SO_4)^{2-}$ (meq/L)	Cl^- (meq/L)	TDS (%)	EC (ms/cm)	Mg^{2+} (meq/L)	Ca^{2+} (meq/L)	K^+ (meq/L)	Na^+ (me1/L)	pH
38.90	10.22	0.6	96.00	13.90	34.8	9.00	174.30	7.2

Table 3 - Aggregation properties of the used soil.

D10 (mm)	D30 (mm)	D60 (mm)	Passing #200	Pas. 0.005(S)	Pas. 0.005(D)	Gs	UNIFIED Cl.	AASHTO Cl.
-	0.200	0.019	91.62	43.96	* 5.92	2.76	CH	A-7-5

*double hydrometric test.

222

Soils and Rocks, São Paulo, 36(2): 221-228, May-August, 2013.

leached water and hole diameter after test (Heidarian, 1993 and ASTM D698- A).

2.1.2. Double hydrometric tests

During these tests, the soil particle size distribution is initially determined by common method of hydrometric test, i.e. using mechanical agitator and dispersing chemical additive. Then it is repeated with another hydrometric test with another sample of the same soil without using mechanical agitator and dispersing chemical additive (ASTM D4221). The percentage of particles finer than 0.005 mm is determined in both tests. Dispersion percentage is defined as the ratio of percentage of particles finer than 0.005 mm in the second test to the first test.

2.1.3. Chemical tests

Dispersion is usually a physical - chemical phenomenon, and chemical properties of soils have important effect on the soils dispersion, particularly type and amount of cations and pore water. Therefore, different criteria have introduced for recognizing the dispersion potential for instance electrical conductivity (EC), pH value, sodium absorption ratio (SAR) and total suspended solids (TSS) (Rahimi, 1989).

2.1.4. Atterberg limit tests

Atterberg limit tests were conducted on samples with the mentioned alum contents as well as other tests (ASTM D4318) and at curing times of 1 to 28 days.

2.1.5. Compaction tests

The influence of maximum dry unit weight and moisture content on soils dispersion potential is not well understood. In some cases, reduction of moisture content results in decrease of soil dispersion and vice versa, and in some cases reduction of moisture content has added increased the soil dispersion. The reason for such incongruity has not been yet determined. Studies have indicated that the way of influencing both factors depends on other factors, such as type of soil, its chemical properties, concentration and type of ions in pore water, soil saturation and compaction energy (Asgari & Fakher1994). For studying the influence of additive content and curing time on the maximum dry unit
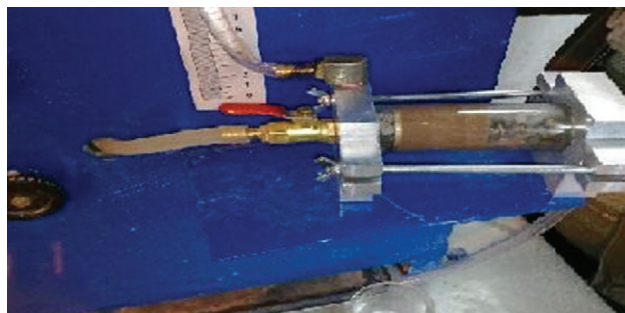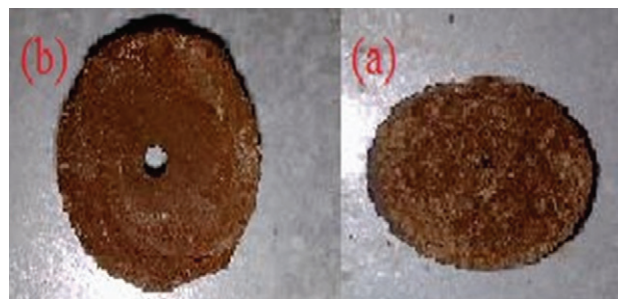

Figure 2 - Pinhole test.

weight as well as optimum moisture content, compaction tests were performed on the soil samples (ASTM D698).

3. Results and Discussions

3.1. Pinhole test results

The hole diameter in the natural soil sample without stabilizer increased for about four times and the leached water color turned to muddy and very muddy indicating the higher dispersion potential (Figs. 3 and 4, respectively). Dispersion rate of samples were considerably decreased by addition of 0.6% alum, such that the diameter of sample internal hole was about half of the natural soil with water color clearer than before (Fig. 5). Water discharged was also reduced in comparison with natural soil. The stabilized soil was categorized as the dispersion class of ND3, meaning low dispersion (In fact, ND3 means a soil slightly

Figure 3 - (a) Non dispersive soil, and (b) Fourfold increase in the hole diameter of dispersive soil.

Figure 4 - The sample of the discharged water from pinhole test for dispersive and non dispersive soils.

Figure 5 - Changes in the dispersive and non-dispersive soils discharged water.

dispersive, suggesting high uncertainty about the existence of significant problems in the design). Continuously, soil was more improved at 1% of additive content. Adding alum from 3 to 10% fully causes the soil to be non-dispersive, the discharged water becomes more clear with no fundamental changes in the diameter of internal hole indicating lack of internal erosion (Fig. 6).

As shown in Figs. 7 to 10, discharged water increases *vs.* water head difference between input and output of the sample. Also, increasing the additive content in a specific water head difference reduces the discharged water. It was observed that increasing the curing time, the soil dispersion is reduced, because it has more opportunity for replacement and ion exchange by time.

As mentioned before, at all percentages of alum, soil's dispersion potential was reduced by increasing the curing time including the clarity of leached water, discharged water and diameter of eroded (Figs. 6 to 10). However, decrease of dispersion was more effective during the first 7 days. Also, for higher percentages of additives, there was non-dispersive soil even in at lower curing times. After 7 days, the rate of dispersion was decreased. Adding of 3 to 5% of alum for initial curing times and of 2 to 3% for 14 to 28 days curing times was considered to be resulted in fully
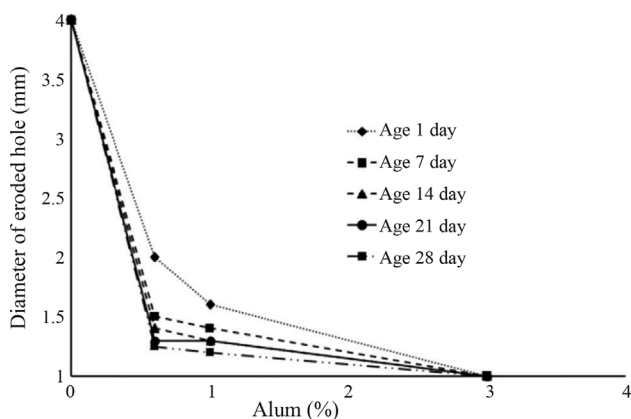
non dispersion soil. Tables 4 to 6 indicate clarity of the leached water from the samples, illustrating the soil improvement trend.

3.2. Double hydrometric test results

Tests results indicated that it is more likely to erode and wash the clay particles with dispersion percentage more than 40. This limit also depends on the type of soil. Decker recommended that this limit is about 40% for the inorganic clay and it is considered about (25 to 30)% in the low plastic mud , clayey and muddy sand (Asgari & Fakher, 1994).

Figure 8 - Discharged water *vs.* alum additives at water head difference of 180 mm.

Figure 6 - Diameter of hole *vs.* alum content at water head of 50 mm.

Figure 9 - Discharged water *vs.* alum additives at water head difference of 380 mm.

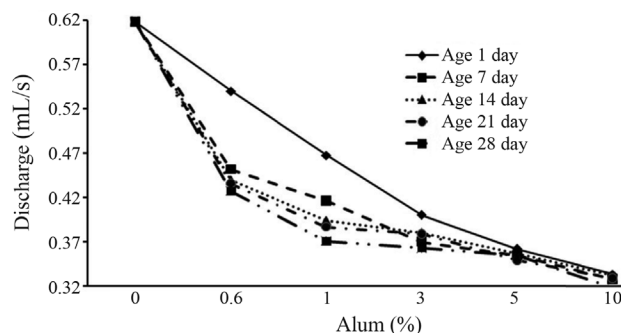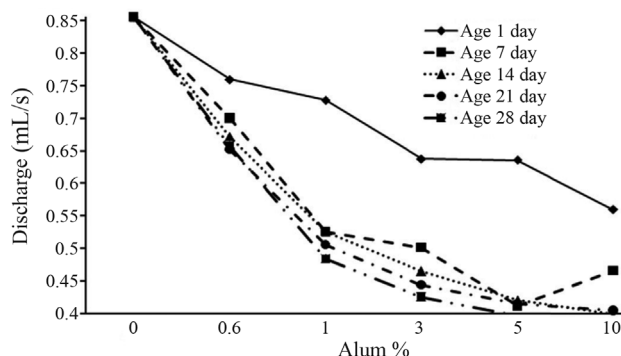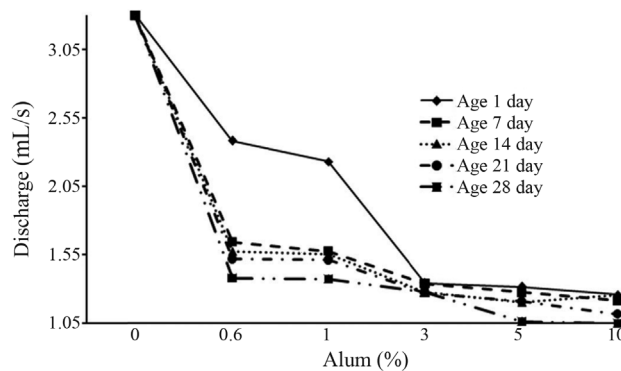**Figure 7** - Discharged water *vs.* alum additives at water head difference of 50 mm.

Figure 10 - Discharged water *vs.* alum additives at water head difference of 1020 mm.

Table 4 - Clarity of the leached water at different curing times, alum additive and water head of 50 mm.

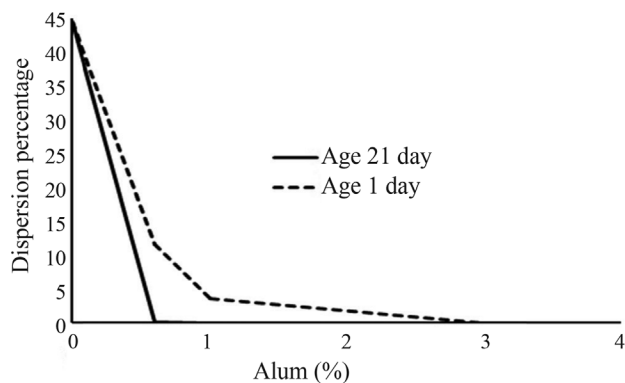| Curing time	Additive (%)					
	0	0.6	1	3	5	10
1 day	A little turbidity	An effect of turbidity	Fully clear	Fully clear	Fully clear	Fully clear
7 days	A little turbidity	An effect of turbidity	Fully clear	Fully clear	Fully clear	Fully clear
≥ 14 days	A little turbidity	An effect of turbidity	Fully clear	Fully clear	Fully clear	Fully clear

Table 5 - Clarity of the leached water at different curing times, alum additive and water head of 380 mm.

Curing time	Additive (%)					
	0	0.6	1	3	5	10
1 day	Averagely turbidity	A little turbidity	An effect of turbidity	Fully clear	Fully clear	Fully clear
7 days	Averagely turbidity	A little turbidity	An effect of turbidity	Fully clear	Fully clear	Fully clear
≥ 14 days	Averagely turbidity	A little turbidity	An effect of turbidity	Fully clear	Fully clear	Fully clear

Table 6 - Clarity of the leached water at different curing times, alum additive and water head of 1020 mm.

Curing age	Additive (%)					
	0	0.6	1	3	5	10
1 day	Very turbidity	A little turbidity	An effect of turbidity	Fully clear	Fully clear	Fully clear
7 days	Very turbidity	A little turbidity	An effect of turbidity	Fully clear	Fully clear	Fully clear
≥ 14 days	Very turbidity	A little turbidity	An effect of turbidity	Fully clear	Fully clear	Fully clear

Increasing of alum and curing time considerably reduced the dispersion potential such that for 1 and 21 days curing time, the dispersion potential became zero for the additive percentages of 3 and 1% respectively (Fig. 11). As indicated in this figure, addition of even 0.6% alum severely reduced the dispersion potential. Experiences have indicated that the results of this test have an accuracy of about 85% when predicting the dispersion of soils. On the other hand, dispersive soils have dispersion percentage higher than 30% (Heidarian, 1993).

3.3. Chemical test results

As illustrated in Fig. 12, addition of alum as well as increasing curing time results in increased EC. This is because of displacement of ionic followed by soil stabilization. According to Fig. 13, adding the alum up to 0.6% increases the pH value and then decreases it. The reason for such increase is producing some acid resulted from ionic displacements. Ignoring the initial values, increasing the alum and curing time generally decreases pH value. Total suspended solid (TSS) in the leached water is reduced by

Figure 11 - Dispersion percentage for curing times of 1 and 21 days *vs.* alum using single and double hydrometric tests.
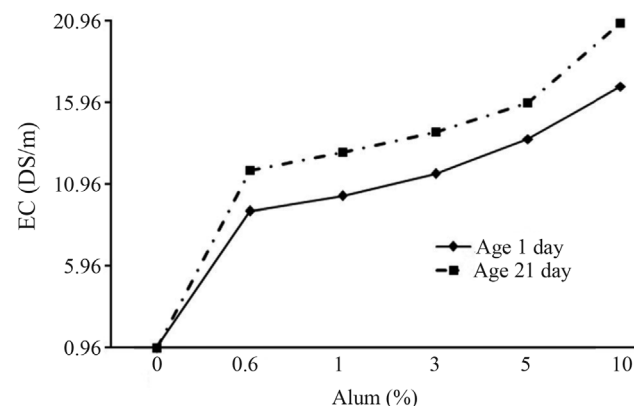
Figure 12 - Electrical conductivity *vs.* alum for curing times of 1 and 21 days.

Soils and Rocks, São Paulo, 36(2): 221-228, May-August, 2013.

225

increasing of alum content and curing time due to preventing of soil particles from escaping and washing (Fig. 14). Finally, according to Fig. 15, replacements of sodium with aluminum cations increases by increasing of alum content and curing time; however, the alum content is apparently more effective in comparison with curing time. Among these, increase of EC and decrease of TSS are considered as the more important criteria for reducing the dispersion (Asgari & Fakher1994).
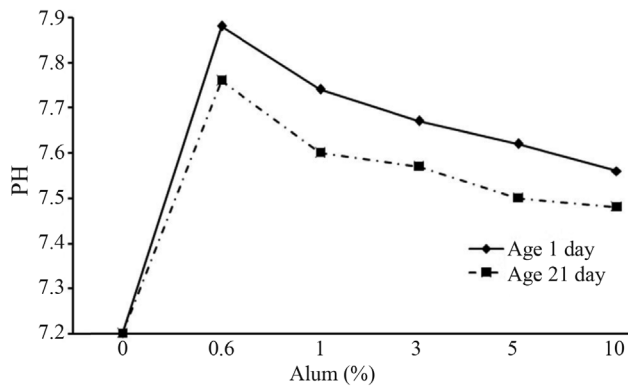

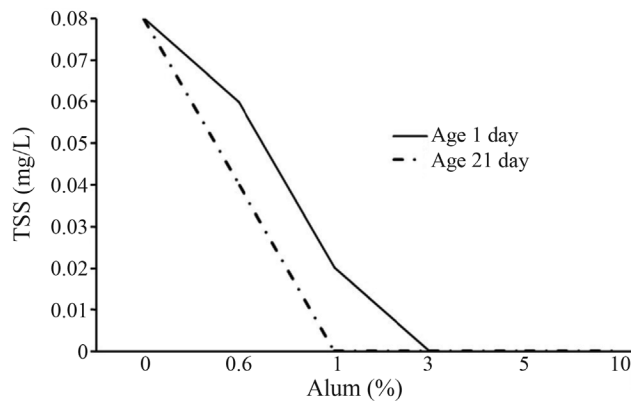**Figure 13** - PH values *vs.* alum for curing times of 1 and 21 days.

Figure 14 - TSS value in the leached water *vs.* alum for curing times of 1 and 21 days.
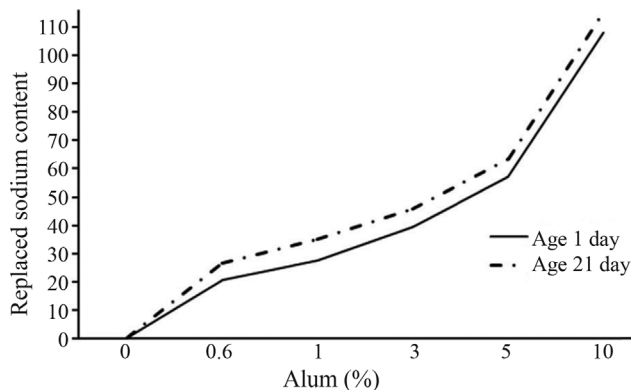

Figure 15 - Ionic exchanges *vs.* alum for curing times of 1 and 21 days.

3.4. Atterberg limit test results

Tests results shown in Figs. 16, 17 and 18 indicate that increasing the alum content and curing time have a regular trend on the stabilized soil. Generally, liquid limit and plasticity index are increased up to 0.6% of additive content and then decreased and plasticity limit indicates an ascending trend. It is seen more changes for plastic limit up to curing times of 7 days, but then, the closer is the changes trend. It was seen observed that increasing curing time decreases the liquid and plastic limits. However, there is no specific relation between soil dispersion and Atterberg limits (Asgari & Fakher, 1994).

3.5. Compaction tests results

Test results as revealed in Fig. 19 and 20 indicate that the changes trend is not very regular but at a glance, adding the alum increases and decreases the maximum dry unit weight (for about 6.2%) and optimum moisture content (for about 11%), respectively, up to alum content of 1%. Then the trend is reversed. Therefore, considering of these two parameters, the best alum additive content is about 1%.
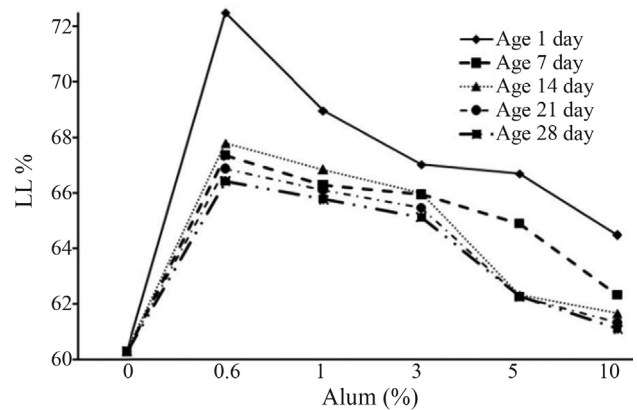

Figure 16 - Changes in liquid limits (LL) for different percentages and curing times.
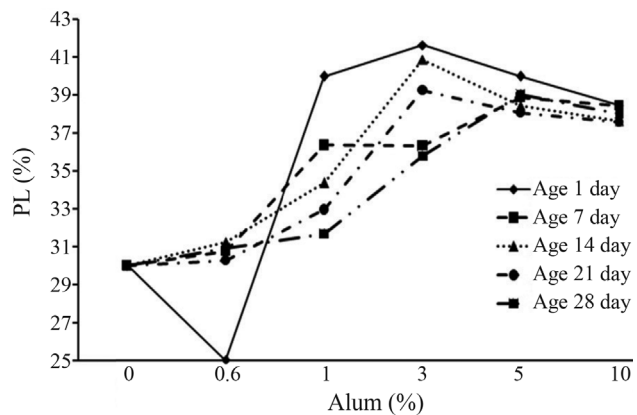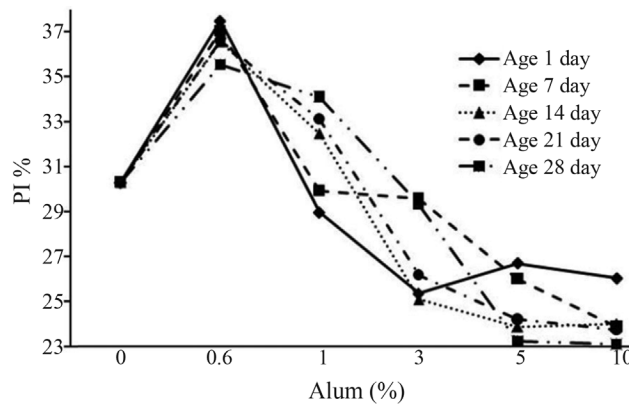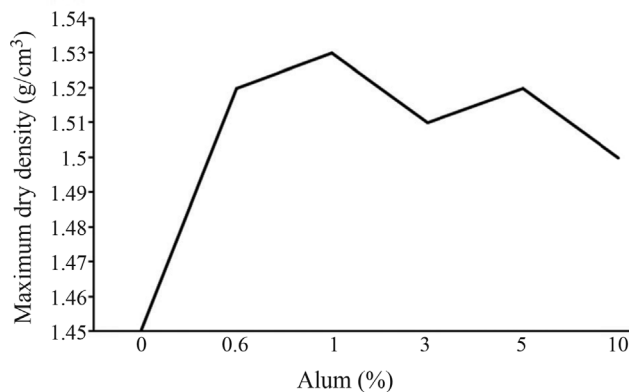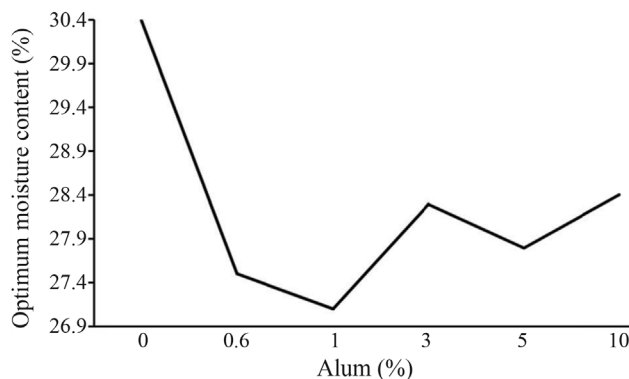

Figure 17 - Changes in plasticity limit (PL) for different percentages and curing times.

Figure 18 - Changes in plasticity index (PI) for different percentages and curing times.

Figure 19 - Maximum dry unit weight *vs.* alum content for curing time of 21 days.

Figure 20 - Optimum moisture content *vs.* alum content for curing time of 21 days.

4. Conclusion

Addition of white alum to a dispersive clay results in adsorption of aluminum ions surrounding the clay particles. Dispersion potential of soil and its modifiability were evaluated using pinhole, single and double hydrometric, chemistry and standard compaction tests. The influence of alum on the Atterberg limits of soil was also studied. Tests results indicated that:

- Pinhole tests indicated that adding the alum and increasing the curing time up to 28 days, under hydraulic gradients up to 26.84, dispersion potential of the investigated soil was decreased.

- For curing time over than 14 days, addition of the alum of about 2-3% of dry weight of soil completely stabilized the dispersion potential of the soil. However, addition of 3% of alum by 3% of soil dry weight turns the soil to a fully non dispersive soil.

- Results of chemical, hydrometric tests indicated a completely positive performance for the process of soil stabilization and improvement.

- Adding the alum and curing time increased the electrical conductivity of the soil and replacement of sodium ion as well, and decreased the suspended materials in the leached water from soil.

- Adding the alum up to 0.6% of dry weight of soil increased the liquid limit and plasticity index and then decreased them. Changes in pH value of the modified soil also indicated a similar trend. Plasticity and liquid limits both were reduced by curing time; however, plasticity index slightly indicated some variations.

- Both the maximum dry unit weight and optimum moisture content indicated relatively irregular changes *vs.* the alum content. Nevertheless, optimum values of the mentioned parameters were obtained at 1% of alum.

References

Asgari, F.A. & Fakher, A. (1994) Soil Swelling and Dispersion from a Geotechnical Engineers Point of View. Jihad Daneshgahi Publications, Tehran University, 245 pp.

ASTM (1998) Standard Test Method for Identification and Classification of Dispersive Clay Soils by the Pinhole Test. D4647. ASTM International, West Conshohocken, Pennsylvania, USA, 11 pp.

ASTM (1999) Standard Test Method for Dispersive Characteristics of Clay Soils by Double Hydrometer Test. D4221. ASTM International, West Conshohocken, Pennsylvania, USA, 3 pp.

ASTM (2000) Standard Test Method for Laboratory Compaction Characteristic of Soil Using Standard Effort (600 kN.m/m^3). D698. ASTM International, West Conshohocken, Pennsylvania, USA, 11 pp.

ASTM (2005) Standard Test Method for Liquid limit, Plastic limit and Plasticity Index of Soils. D4318. ASTM International, West Conshohocken, Pennsylvania, USA, 16 pp.

ASTM (2007) Standard Test Method for Particle size Analysis of Soils. D422. ASTM International, West Conshohocken, Pennsylvania, USA, 8 pp.

Heidarian, H. (1993) Standard Methods of Soil Mechanics Laboratory Tests. Avand Andishe Publications, Tehran, pp. 64-70.

Ouhadi, V.R. & Goodarzi, A.R. (2006) Assessment of the stability of a dispersive soil treated by alum. Engineering Geology, v. 8, p. 91-101.

Rahimi, H. (1989) Water structural problems in salty and chalky soils (Case Study - irrigation system of Gotvand project). Iranian Journal of Agricultural Sciences, v. 21, p. 93-109.

Ryker, N.L. (1977) Encounting dispersive clays on soil conservation service projects in Oklahoma. ASTM STP, v. 623, p. 370-389.

Sherard, J.L.; Decker, R.S. & Ryker, N.L. (1972) Piping in earth dams of dispersive clay. Proc. of Specialty Conf. on performance of earth and earth supported structures. ASCE, v. 1, Part 1, pp. 589-626.

Sherard, J.L. & Decher, R.S. (1977) Summary - Evaluation of symposium on dispersive clays. ASTM STP, v. 623, p. 467-479.

Vakili, A.H.; Zomorrodian, M.A & Vakili, A. (2009a) Evaluating dispersion potential of dispersion clays, stabilized by pozzolans. Proc. 8th International Congress of Civil Engineering, Shiraz University pp. 141-148.

Vakili, A.H.; Zomorrodian, M.A.; Vakili, A & ARAM, M. (2009b) Evaluating dispersion potential and physical-mechanical stabilized by lime and pozzolan. Proc. 8th International Congress of Civil Engineering, Shiraz University, pp. 232-240.

List of Symbols

CH: High plastic clay

pH: power hydrogen

EC: Electrical conductivity

SAR: Sodium absorption ratio

TSS: Total suspended solids in the leached water

Gs: Specific gravity

Cl: Clay

TDS: Total dissolved solids

ASTM: American society for testing and materials

LL: Liquid limit

PL: Plastic limit

PI: Plasticity index

228

Soils and Rocks, São Paulo, 36(2): 221-228, May-August, 2013.