Pollution, 5(2): 411-418, Spring 2019
DOI: 10.22059/poll.2018.261145.472
Print ISSN: 2383-451X Online ISSN: 2383-4501
Web Page: https://jpoll.ut.ac.ir, Email: jpoll@ut.ac.ir

Capability of Reused Waste from Aluminum Industry (Red Mud) in Iran to Improve Compressive Strength of Loose Soil

Daryabeigi Zand, A.,[*] Rabiee Abyaneh, M. and Hoveidi, H.

School of Environment, College of Engineering, University of Tehran, Tehran, Iran

Received: 03.04.2018 Accepted: 29.09.2018

ABSTRACT: Jajarm Alumina Plant, the only Alumina powder producer in Iran, generates 500,000 tons of red mud annually. The commonest method for final disposal of red mud in Iran is Tailing dam which is neither cost-effective nor environmentally-friendly. The main objective of this study is to evaluate the possibility of red mud recovery to be used for stabilization of loose soils. Red mud samples have been collected from tailing dam of Jajarm Alumina Plant to be characterized, using X-Ray Fluorescence (XRF). The soil stabilizer has been made by mixing red mud, steel slag, sodium metasilicate, and sodium hydroxide. In order to study the effect of soil stabilizer, five soil samples have been prepared which contain clay, sand, and wind-blown sand ranging from zero to 4 millimeters. Findings show that adding soil stabilizer with red mud significantly enhances compressive strength of soil samples (4.2, 18.2, 5.4, 4, and 4.1 in S1 to S5 samples, respectively). Also the results demonstrate that the red mud, produced from Aluminum industry in Iran, might be successfully used to stabilize loose soils, thereby enhancing their compressive characteristics, reducing environmental issues associated with uncontrolled disposal of such wastes as well as promoting integrated solid waste management strategies.

Keywords: waste management, aluminum industry, red mud, compressive strength, soil stabilization

INTRODUCTION

Due to rapid industrialization and infrastructure development, large amounts of industrial waste materials are produced every year. They require safe disposal, demanding large areas of land for doing so, which leads to environmental pollution. Aluminum production industry is not an exception (Deelwal et al., 2014; Perez-Villarejo et al., 2012; Ujaczki et al., 2016; Toniolo et al., 2018; Tang et al., 2018; Zhang et al., 2018). Red mud, a by-product of sodium hydroxide and bauxite reaction, is the solid waste, generated during the Bayer process of alumina extraction (Liu & Naidu, 2014; Lui & Poon, 2016; Feng et al., 2016; Hu et al., 2018; Yang et al., 2018). This industrial waste is generated in very large quantities (Carneiro et al., 2018; Power et al., 2011; Zhu et al., 2017; Singh et al., 2018; Deng et al., 2018). To further illustrate the point, it is worth noting that the production of just one ton of alumina generates between 1 and 2 tons of red mud (Huang et al., 2016; Zhu et al., 2017; Li et al., 2016; Lemougna et al., 2017; Celik, 2017). The alumina industry produces more than 120 million tons of red mud annually and approximately 3 billion tons of it has already been stockpiled since 1890

[*] Corresponding Author Email: adzand@ut.ac.ir

when the Bayer process started industrially (Hegedus et al., 2016; Borra et al., 2016; Abdulvaliyev et al., 2015; Borra et al., 2015; Li et al., 2018). Disposal of red mud requires a huge land, abundant earth material, large costs, and further monitoring. Also, because of its high alkalinity, red mud poses significant risks to the local environment, like air pollution, surface water and ground water pollution, and soil infertility (Huang et al., 2016; Li et al., 2016; Kurtoglu et al., 2016; Nie et al., 2016; Liang et al., 2018).

Similar disposal methods are being used around the world, e.g., landfill, deep sea dumping, and storage in settling ponds (Liu & Naidu, 2014; Samal et al., 2013; Liu et al., 2011; Tang et al., 2018; Scribot et al., 2018). Several studies have been conducted in order to find a way for red mud utilization. For example, its use as an adsorbent for pollutant removal, a catalyst, or building materials. Recovery of metals and rare earth elements is another solution under investigation (Panda et al., 2017; Liu & Naidu, 2014; Li et al., 2014; Cao et al., 2013; Hegedus et al., 2018; Shim et al., 2018; Kucukdogan et al., 2018; Wang et al., 2018).

Soil stabilization refers to the process of changing soil properties in order to improve its strength and durability (Mane & Rajashekhar, 2017; Afrin, 2017; Suresh et al., 2018), which can be accomplished via several methods. Under chemical stabilization category, unbound materials can be stabilized with cementitious materials (cement, lime, fly ash, bitumen, or a combination of these) (Aswathy et al., 2016; Gowtham & Janani, 2017). Red mud has been chosen as an admixture for a study of its effectiveness on expansive soil treatment, nowadays (Pandey & Jawaid, 2015; Gowtham & Janani, 2017; Mane & Rajashekhar, 2017); however, there is no report on its utilization in soil stabilization in Iran. As such, the main objective of this research is to evaluate the improvement of a compressible soil's strength by utilizing the red mud in combination with other chemical stabilizers such as fly ash, sodium metasilicate, and sodium hydroxide.

MATERIALS AND METHODS

The red mud, used in the experiments, was collected from the tailing dam of Jajarm Alumina Plant, the only producer of alumina powder in Iran. The plant is located 5 km from Jajarm city in Northern Khorasan province, Iran, between 36°99'31.55" N and 56°44'09.83" E. By discovering considerable amounts of bauxite in Jajarm city and the vast contribution of the United Nations Industrial Development Organization (UNIDO), the only alumina production plant in Iran was founded in 1983, ultimately to open in 2003. Figure 1 illustrates the location of Jajarm Alumina Plant (in red color) and its tailing dam (in yellow color).

Jajarm Alumina plant turns the bauxite mineral, extracted from the bauxite mine, located some two km off the plant, into alumina powder. In order to produce alumina, it employs tube digestion method, in which by means of Programmable Logic Controller (PLC) system, pneumatic sampling unit and the central laboratory go under automatic control. In this method the transported bauxite from the mine is crushed in two stages to obtain 20 mm size particles. Afterwards, bauxite, lime, and soda are milled by the wet method so that a bauxite ore slurry with suspended particles, sized 0.009 mm, can be generated. The bauxite slurry is desilicated and kept in the desilication unit. Then vaporization is performed at the tube digestion unit. Initially, the slurry temperature is increased up to 250°C, then with the substance passed through the oven and reactor, the temperature is further increased up to 314°C. Through the high pressure and temperature values, the existing alumina in bauxite is dissolved in soda and the other part remains as waste in the slurry. After being diluted, the cooled slurry is divided into two streams of aluminate liquor and

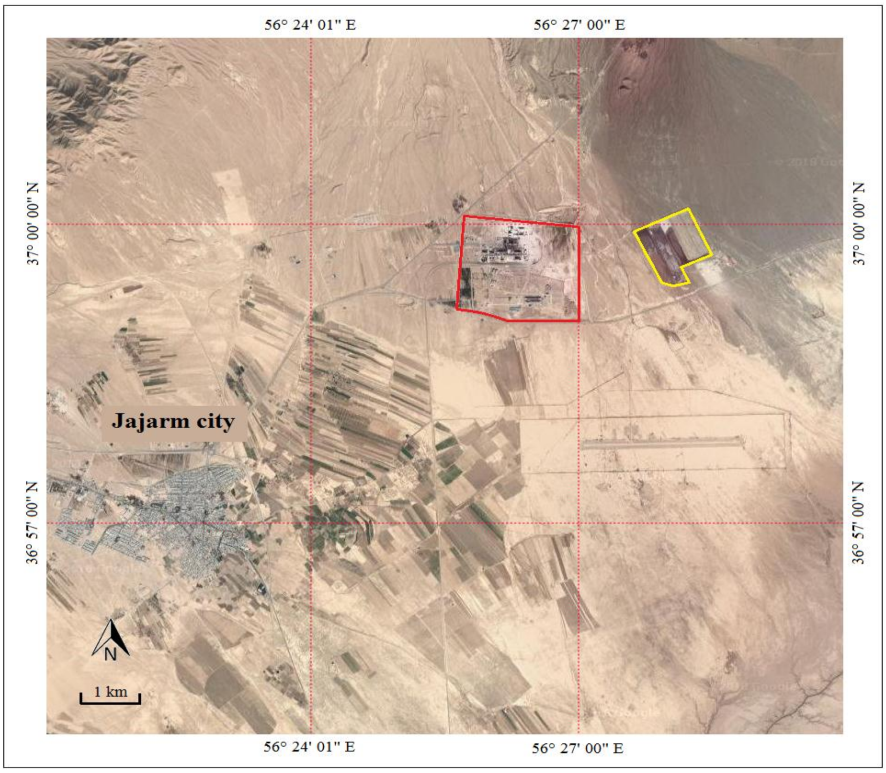

Fig. 1. Location of Jajarm Alumina Plant and its tailing dam

red mud, with the obtained aluminate liquor converted to aluminum hydrate,using sedimentation and crystal growth methods. It is transported and deposited after being washed and refined. Then it is transported to the oven with a temperature ranging from 1150°C to 1250°C so that it will lose its water content. That is how the products of Jajarm Alumina Plant, namely aluminum oxide (alumina), aluminum hydroxide (hydrate), and alpha alumina are prepared. Red mud is transported to the tailing dam located 3 km east of the plant. It is a ring-type dam, containing five rectangular-shaped bands where piping is supplied throughout their walls to discharge red mud. The production capacity of the Jajarm Alumina Plant amounts to 280,000 tons of alumina per year and the plant also generates 500,000 tons of red mud each year, according to the design capacity (Zarbayani et al., 2010; Chehreh Chelgani & Jorjani, 2009).

For the present study, red mud samples were taken from different places in the tailing dam of Jajarm Alumina Plant. The samples were dewatered via filter presses and room temperature drying and got further dried at a temperature of 105˚C prior to grinding. For chemical characterization of the red mud, samples were sent to Razi Metallurgical Research Center for X-Ray Fluorescence (XRF) analysis. Table 1 gives the results of Jajarm red mud XRF analysis. Moreover, the particle size analysis showed that almost 80% of red mud particles had dimensions, smaller than 30 μ.

Table 1. XRF analysis of Jajarm red mud

Compound	Weight (%)
Fe_2O_3	23.7
SiO_2	18.3
CaO	15.1
Al_2O_3	14.8
Na_2O	8.2
TiO_2	5.1
MgO	1.4
K_2O	0.72
ZrO_2	0.2
SO_3	0.19
P_2O_5	0.18
ZnO	0.16
V_2O_5	0.095

The soil samples, studied in this work, were collected from Tash village, near the city of Shahrud in Semnan Province, Iran, along the access road to Jajarm Bauxite Mine, Jajarm city, North Khorasan province, Iran. It had the following compounds, as shown in Table 2.

The fly ash, used in this study, was provided from Esfahan Steel Company Steel Slag, Isfahan province, Iran. Chemical characterization of Isfahan steel slag was carried out the same as red mud through XRF analysis with the results presented in Table 3. Also, alkalinity (CaO/SiO_2) for steel slag sample was measured equal to 1.03.

Table 2. Compositions and properties of soil samples

Sample number	Compounds
S1	Gravel clay
S2	Wind-blown sand
S3	Wind-blown sand and clay
S4	Sand with particle sizes ranging from 0 to 4 mm and clay
S5	Sand with particle sizes ranging from 0 to 4 mm, wind-blown sand and clay

Table 3. XRF analysis of Isfahan steel slag

Compound	Weight (%)
CaO	35.48
SiO_2	34.64
MgO	11.54
Al_2O_3	10.28
TiO_2	3.44
S	1.09
MnO	0.92
FeO	0.73
V_2O_5	0.08

Table 4. The amount of substances to prepare soil stabilizer

Substance	Weight (gr)
Jajarm red mud	50
Isfahan steel slag powder	50
Sodium metasilicate	15
Sodium hydroxide	5

That single phase made stabilizers more feasible to operate in this study, while moisture-free compounds (with maximum 1% moisture) such as sodium hydroxide or perk and sodium metasilicate were viable options. Table 4 demonstrates the combinations with appropriate mixers.

All samples got prepared, based on ASTM-D2166 standard method (ASTM, 2006). After mixing the substances with the above-mentioned weight in the dry powder mixer, the same amount of soil stabilizer (15% of dry weight) was added to soil samples. After adding water, the samples were compacted in 3-house brass molds, 5×5×5 cm in dimension, and set in room temperature. As for quick fixing, the molds were opened after 4 hours and the samples were cured in the open air with water sprinkled over it for three times. The samples were sent to Irankhak consulting engineers to measure their Unconfined Compressive Strength (UCS). In order to evaluate the effect of soil stabilizer, the samples got prepared once more, this time without addition of the soil stabilizer. They were then sent to the mentioned laboratory for the same test. All tests were conducted in triplicate in order to verify the findings' quality.

RESULTS AND DISCUSSION

Figure 2 demonstrates the variation of UCS in soil samples before and after adding the soil stabilizer.

Figure 2 reveals that the UCS of samples with soil stabilizer content was significantly increased in comparison to those without soil stabilizer. As can be seen, addition of soil stabilizer increased the UCS of S1, S2, S3, S4, and S5 by 4.2, 18.2, 5.4, 4, and 4.1 folds, respectively. Soil stabilizer converts the atomic bonds of aluminum and silice from divalent oxide and trivalent oxide into polymer bonds. Aluminum and silica particles are joined to each other, forming four polymer bonds as well as the long polymer chains of these primary monomers. Despite other processes wherein soil particles are physically connected, here the binding of soil particles occurs due to atomic bonds, leading to the creation of different compressive strengths in soil samples which commensurate with formation grade of corresponding atomic bonds.

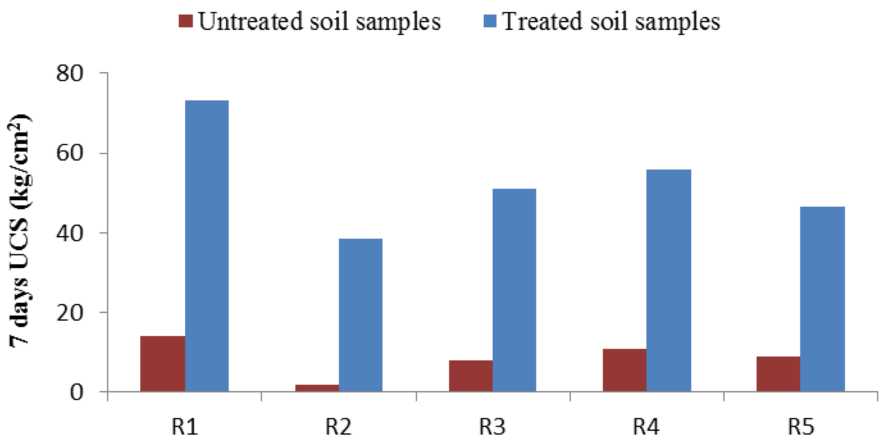

Fig. 2. Variation of UCS in treated and untreated soil samples

Although the red mud does not contain amorphous phases and cannot be considered an amorphous structure, and the crystal phases are not involved in the polymerization process, this waste can be served as inactive fillers in polymer lattice to boost the polymer bonds in amorphous phases desirably. Therefore, according to the composition of red mud (Table 1), including silice and alumina, with high pH and very fine particle size, it can be used for soil stabilizer production. The stabilization is based on formation of inorganic polymers in geopolymerization process along with the addition of other materials like steel slag, sodium metasilicate, and sodium hydroxide to red mud. Some types of polymers, formed through the reaction of aluminosilicates in alkaline environment, have remarkable mechanical, physical, and chemical properties. A reaction between silica-rich and alumina-rich environments, on one hand, and a highly alkaline solution, on the other, produces a composition of jelly and crystalline compounds. Over a period of time, this structure becomes stronger and a new and strong lattice is created. In a pozzolanic geopolymer reaction, this polymer consumes a large amount of waste (such as red mud and steel slag) as a feed. With the help this polymer, many alumina silicate wastes can be converted into construction materials with the highest physical and chemical properties as well as a long-term stability.

A similar observation was reported by Pandey & Jawaid (2015), who utilized red mud mixed with fly ash in soil stabilization and found that when mixed with fly ash red mud improved the strength of low bearing soil. In this regard, the study by Gowtham & Janani (2017) revealed that the use of red mud as a stabilizing material can enhance UCS of clay soil. Also, Mane & Rajashekhar (2017) studied the stabilization of black cotton soil by utilizing red mud and sodium silicate. They reported that improvement of black cotton soil can be achieved by adding red mud and sodium silicate. Therefore, by using the red mud as a waste of aluminum industry, steel slag as a waste of steel industry, and strong alkaline such as sodium hydroxide and sodium metasilicate, a useful material can be produced for stabilization of a wide range of soils. Also the use of red mud for soil stabilizer production manages to eliminate a large amount of this waste, while tackling environmental problems.

CONCLUSIONS

The current study presented the potential use of red mud for soil stabilizer preparation. To do so, at first Jajarm red mud and Isfahan steel slag were characterized by XRF analysis. Then the appropriate amount of substances, including red mud, steel slag, sodium metasilicate, and sodium hydroxide, was determined for preparation of the soil stabilizer. Five soil samples were prepared and their UCS was measured, once with and once without the addition of the soil stabilizer. Results showed that in all samples, addition of the red mud significantly increased the compressive strength (by 4.2, 18.2, 5.4, 4, and 4.1 folds in S1 to S5 samples, respectively). It can be concluded that the red mud-containing stabilizer can improve and consolidate a broad range of loose soils. From this point of view, it can also boost the durability and soil compressive strength, improve the strength of loose soils, prevent penetration, and decrease the permeability, plasticity range, swelling, and shrinkage of soils. Furthermore, it can form foundation layers with more bearing capacity, reduce the thickness of pavement layers, accelerate the operation and construction of cost-effective roads, increase the efficiency, improve the machinery function, and reduce the amount of fuel consumed during the road construction. What is more, the recovery of red mud as a hazardous industrial waste and its transformation into a usable and non-toxic new material contributes to the protection of environment. The study added the soil stabilizer to the soil samples in 15% of dry weight due to the quantitative criteria and economic justification for use of low rates. It is pretty recommended to use different soil mixing rates in future researches. Also, in order to ensure environmental safety, some environmental leaching tests like Toxicity Characteristic Leaching Procedure (TCLP) would be useful.

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