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Potential Application of Sludge Pond Ash as A Novel Additive for Clay Stabilization

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ABSTRACT:
*Clays often have unfavorable geotechnical properties that limit construction applications on them. There is a need for sustainable soil improvement techniques to enhance the strength and stiffness of clays. While previous studies have explored clay stabilization with common supplements like cement, lime and fly ash, the utilization of sludge pond ash (*SPA*) as a sustainable additive has been limited and there is a lack of understanding of the interactive effects of* SPA *proportion, moisture content, and curing time on the mechanical behavior of clay. The objective of this study is to examine the mechanical properties of clay enhanced with* SPA *under different curing conditions. To achieve this, different proportions of* SPA *were mixed with the clay to obtain accurate findings on the efficacy of* SPA *addition on compaction and unconfined compressive strength (*UCS*) of the clay to determine mechanical properties. Scanning electron microscopy (*SEM*) provided imaging of clay improved with* SPA *to evaluate the microstructural changes in soil texture. Firstly, the sludge from a pond burned at 1000 °C (the optimal temperature determined by microstructural X-ray diffraction (*XRD*) analysis) was added to the mixture as 0, 2, 4, 6, 8 and 10% of the soil's dry weight, respectively. The studied samples were prepared with the same energy (equivalent to the standard Proctor test) at different moisture contents and were tested in a uniaxial device at 7, 28 and 56 days of curing. It was found that adding* SPA *to the base soil decreased the maximum dry unit weight (*MDUW*). On the other hand, it increased the optimum moisture content (*OMC*) of the compacted mixture. The study examined the combined effects of moisture content and curing time on the compounds, revealing that these factors induced a decrease and an increase in the* UCS*, respectively. The addition of* SPA *as an additive material to the clay mixture was found to exert a significant effect on the strength properties of the clay, with an optimal percentage of around 10%. Empirical correlations were also developed to predict the* UCS *of the* SPA*-improved clay with high precision. Furthermore,* SEM *analyses show that* SPA *acts as a glue gel between aggregate in the mixture and coat clay particles that changes the blend texture and alters weak bonding to aggregate-like particles. The results of both macro- and micro-scale analyses collectively confirm the superior efficacy of the optimal* SPA *replacement in enhancing various strength and stiffness properties of the clay.*

I. INTRODUCTION

During seasonal climate changes, clay deposits are known for absorbing or losing water, leading to significant volume changes and loss of bearing capacity. The behavior of clay soils is affected by small changes in moisture content. These changes in clay particles can cause soil instability problems, including swelling, subsidence, and dispersing. This engineering behavior is highly complex and uncertain. The mechanism is a function of various factors such as the mineral composition, the chemical characteristics of the pore fluid around the clay mineral particles, and the type of bonds between the particles, which cause different behaviors in these types of soils (Goodarzi and Salimi 2015).

Clayey soils generally exhibit some weak engineering characteristics such as low strength, high compressibility, as well as low efficiency and bearing capacity (Asgari et al., 2015). One of the most challenging aspects of geotechnical engineering design is the construction of structures on problematic clays (Pourakbar et al., 2015). Clay stabilization with conventional materials, such as cement and lime, significantly improves the mechanical and physical properties of soils (Rao and Shivananda 2005; Chemeda et al., 2015; Vitale et al., 2016). The stabilization process chemically changes the structure of clays and creates stiff bonding between soil elements in the porous media of the soil. With the introduction of the stabilizer to the clay matrix, preliminary chemical modifications such as cation exchange and carbonation are supposed to occur in a few hours, because of the compression of the diffused double layer. As the stabilization process continues, pozzolanic reactions commence, as a result of which several cementitious products (e.g., *C-S-H* and *C-A-H*) are formed (Negi et al., 2013; Jawad et al., 2014).

Cemented clay is primarily used as a base material and concrete pavement. Besides, it is employed in upstream slope protection for dams, protection of riverbanks and associated structures; canals, reservoirs and wetlands; and compaction practices for dyke and foundation stabilization. In this way of clay stabilization, cement is added to the soil and chemically reacts with the soil and changes the soil's behavior to brittle behavior.

Despite the investigations conducted on these conventional additives, researchers are always looking to replace cement with new high-quality materials due to their geo-environmental constraints and the irreparable risks of producing these materials for the environment. It is noteworthy that the production of Portland cement demands high energy on the one hand, and on the other hand, it emits a lot of greenhouse gases. Consequently, one ton of CO_2 enters the atmosphere for every ton of cement produced. Therefore, excessive use of these traditional stabilizers can severely endanger the environment and human health (Vakili et al., 2022). Recently, studies conducted in this direction showed that non-traditional additive materials such as various industrial wastes and sludge ash can play an essential role in environmental issues in addition to being cost-effective (Yadollahi et al., 2015). New additives with similar characteristics to lime or cement ones. Therefore, examining the effects of various types of industrial waste and sludge ash on the mechanical properties of soil become more popular. The main use of these additives in the soil is to reduce the consumption of lime or cement, increase strength, improve efficiency, reduce permeability, economic efficiency and increase resistance to the attack of sulfates and acids (Goodarzi and Salimi 2015; Salimi et al., 2021).

Recently, some studies used different types of sludge ash to improve soil properties such as carbide calcium residue (Latifi et al., 2018), fly ash (Deshpande and Puranik 2017), palm oil fuel ash (Pourakbar et al., 2015), groundnut shell ash (Sujatha et al., 2016), rice husk ash (Anwar Hossain 2011), silica fume (Goodarzi et al., 2016), burned wastewater sludge ash (Al-Sharif and Attom 2000), wastepaper sludge ash (Rahmat and Ismail 2011), and sludge ash of wood and paper mill (Shirvani and Noorzad 2020).

Generally, sludge ash has the possibility of pozzolanic activity (reaction between a pozzolan, water and $Ca(OH)_2$ in the mixture) (Snellings et al., 2013). Such activity is highly dependent on a number of factors such as particle size, cation exchange capacity (*CEC*), the chemistry of particles, and *Si/Al* ratio. Using sludge ash as the main stabilizing agent might have a quite slow hydration rate in the soil medium for the required enhancement of chemical activators (Estabragh et al., 2020).

Sludge of pond (*SP*) is one of the sediments that can be employed as a stabilizer additive. The sediments of ponds are generally in the range of sand to clay, which on average consists of about 35% calcium and 30% organic particles. This material can be turned into ash and used as a new stabilizing additive by burning at high temperatures (Gupta et al., 2020). Table 1 summarizes the various types of additives and pond ash (*PA*) used in the last decade for clay stabilization.

Prior studies on clay stabilization have not systematically evaluated the combined effects of *SPA* addition, moisture content (*w*), and curing time (*t*) across macro and micro scales. Also, optimal *SPA* proportions and burning temperatures were lacking. Therefore, this study has investigated the effects of sludge pond ash (*SPA*) from Gorgan Gulf on the mechanical properties of fine-grained soil.

The main challenge in collecting and removing *SP* from Gorgan Gulf is the large volume of *SP*, which must be discharged in a suitable place so that the ecosystem of the region does not undergo changes. Collecting and transporting sediments is an expensive process. Therefore, these sediments must be transported and discharged close to the collection site. Consequently, it will return to the bay again due to hydrodynamic currents after a short time. This can lead to ineffective sediment erosion and repeating the extraction process will be needed. Land loading and transportation also require access to vast lands to the purification site. Therefore, this method is not suitable and prioritized for in-site implementation. Hence, a design should be planned so sediments can be used optimally not to harm the environment. One of these plans is to burn and apply them in soil improvement projects, which is the main topic of this research.

It is noteworthy that the southern and western deposit of Gorgan City is clays, which are generally unsuitable for construction, and it is suggested to be stabilized before construction on this type of soil. Therefore, as a solution, it is considered to use the *SPA* from the burning of these sediments as an additive to increase the strength of clay.

II. MATERIALS AND METHODS

This section presents the geotechnical characteristics of the employed materials, including clay and *SPA*, sample preparation, and discusses the procedure of compaction and unconfined compression tests.

III. COMPACTION

The results of the compaction tests on the studied soil mixed with *SPA* are shown in Fig. 5. As shown in Fig. 5a, with the increase of the moisture up to the *OMC*, the dry unit weight of the soil increases to the *MDUW* and then decreases. The variation *MDUW* and *OMC* is shown in Fig. 5b. As can be seen in Fig. 5b, the *MDUW* and *OMC* of the mixture decreases and increases with the increase of *SPA,* respectively. The compaction of mixed materials is related to the grain size of soil particles, specific

IV. CONCLUSION

In this study, the effects of *SPA* stabilization on some of the critical strength and stiffness properties of clay are examined through various geotechnical testing procedures. Macro-level investigations were performed and it was concluded that *SPA* modification can significantly strengthen weak soils. The results of this study could be a significant contribution to the modification of clays. The following results summarize the major findings of this study:

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