A research on strength improvement of clay with mine tailing

Veena Vijayan L¹ and J Prakash Arul Jose²

¹Department of Civil Engineering, Noorul Islam Centre for higher Education, India
²Civil Engineering, Ashoka Institute of Engineering & Technology, Hyderabad, India

E-mail: vee3606@gmail.com, prakashjose11@gmail.com

Abstract. Tailings seem to be the materials left over after the separation process of the desirable fraction from the uneconomic fraction of an ore. A vast quantity and diversity of mine tailings are created everyday around the world. The tailings very often contain heavy metals, chemicals and toxic substances that may disperse into the ecosystem and endanger public health during mineral processing. Those mining waste should be managed properly. To assess these problems, it is necessary to ascertain the appropriate engineering properties of the tailings. A series of experimental studies were performed to determine the geotechnical properties of mine tailings to evaluate the applicability of these materials for construction purposes to undertake this project. The specific index and engineering properties of the soil were calculated by various laboratory experiments. Chemical analyzes were carried out, too.

Keywords: Mine tailings, Hydraulic conductivity, Index properties, Engineering properties.

1. Introduction
The immense utilization of mineral resources generates large quantities of mining waste, generally in slurry with a high content of water and with compressibility. The amount of waste produced has greatly increased in recent decades, as high demand for metals and minerals has increased from time to time, and many low-grade ore have been undermined. Chemicals, heavy metals and toxic substances, which can be dispersed into the nature (environment) that will endanger the public health that is contained in the tailings. Furthermore, the tailings mechanical stability poor in mass, given grain size is small and content of water is high on that. The treatment and handling of waste thus is a major problem for the mining and milling industry as a whole. A number of ways for extracting the waste, including the disposal of thickened or dry residues in floorings and standby dumps, the re-plantation of underground mine operations and with most commonly used method of disposing of tailings in the impoundments involving the transportation of tailing material in loading pipes to a powerless impoundment are proposed for the maintenance of regular mining activities. Increase in mining activity to meet the growing demand for metals and mines, tailing barriers have risen rapidly and numerously. Global tailings have more than 18,400 barrages. The rate of failure of heat-dressing dams which has caused increasing awareness about improving safety in designing and operating heat-damps, which depend heavily on the cyclic and static characteristics of heat-damping dumps and on the geological and hydro-geological conditions at the dumping site. Many studies were undertaken to understand the mechanical properties of the mines. When different types of tailings were analyzed, their results were varied. In addition, the features of the waste are very different and depend heavily on the form of rock, the physical and chemical processes and clay mineralogy for the production of the product that is economically compatible. For designing a tailing dam, it is therefore important to have
an overall understanding about the mechanical properties of every tailing. Furthermore, numerical simulations have proven helpful for the analysis of deformation, seismic reaction filtration and the stability of tailing dams. The necessary input parameters are typically obtained from laboratory tests for such numerical simulation. With the rise in mining operations, the rise for the worldwide demand for metals and minerals is being tackled quickly. Worldwide, there seem to be over 18,400 tailing dams. The high error rates in tailing dams led to increased concern about further need for the greater protection in the design and operation of tailing dams based heavily on the stable and exponential features of the tailing dams used to build them. Several experiments were conducted to assess the mechanical properties of the tailings, with various types of tailings studied. Indeed, the features of waste are very different and highly dependent on the type of ore, the mineralogy of clay and the physical and chemical methods used for economic commodity production. Thus, a thorough understanding of the physical behaviour of my tailings is important to build a tail dam. However, simulation model is a valuable method in analyzes of inhalation, deformation, seismic response and the stability of tailing barriers. The required input parameters are typically obtained from laboratory tests for such numerical simulation.

For manufacturing industries, mining industries are important. Mining pushes and produces large quantities of rock and tailings. Thin grained ones are the mine tailings, un-economic mineral residual content. Tailings are held in large warehouses. With the production rate increasing each year, a large number of mined wastes are disposed of in tailings dams. Around 370 tons of mining dust is created with one ton of metal, which is having 0.3% ore grade and 90% recovery total. The environmental protection agency (EPA) in toxic release inventory stated in 2000, the hard-rock mining is one of the industries which are having the biggest toxic waste producer of that year, which has released 1.5 million metric tons, means 47 percent of the total waste generated in US industry. The disposal of an immense mass of tailoring materials regularly generated from the mining operations is a common environmental problem in the mineral industries. Mining companies have historically not had a strong reputation for releasing their waste to the natural community. Tailing dams have played a significant role in securing critical soil and water supplies against polluted slurries as a practical solution. Tailings dams are called the world's largest architectural structures. They typically consist of three kinds of material: (1) sediment factory (2) mine tailings (3). Significant water bodies can usually be held behind residue dams, so that a compromised failure may result in serious damage to life, property and environment. The design, construction and operation of these barriers therefore require a high level of engineering care.

Traditional methods for mine tailings disposal are to refill deep voids for industrial mining and surface mining recovery. Such forms of rectification, which only "dump" the mines into the rubbish, do not fix the issues entirely. Problems including vast land mass, leaching of heavy metals, contamination and with potential possibility of the failure of the tailing dam remain. For some mines, dry stacking tailings technology is being applied to provide further recovery options. As we are conscious, the synthesized tailings having heavy metals like copper, arsenic, molybdenum and uranium that pollute ground water and soils, endanger plant life. If the mine tailings are to be recycled, heavy metals must be encapsulated and immobilized.

2. Background
Liming Hu and Qingbo Wen[10] studied about the geotechnical properties of mine tailings. Analytical experiments were carried out in this study to examine the properties (geotechnical) of different tailings namely four, namely iron of two (coarse and fine) tailings and two (coarse and fine) tailings having copper. The iron tails displayed higher compressibility, strength having low ones and with the lower cyclic resistance than the copper tailings. The decreasing void ratio, the consolidation coefficient almost kept constant in fine iron residues, while the coefficient of consolidation gradually increased in the fine copper residues. Geotechnical properties of copper mine tailings have been studied by Abolfazi Shamsai, Ali Pak [1]. Waste management is becoming increasingly relevant in the industry. The building of a tailing dam plays a significant role in this regard. Most of the tailing dams require certain kinds of corrective measures during their operating lifetime. Yunxin (Jason) Qiu and D.C. Sego [17] studied mine tailings laboratory properties. A variety of experimental experiments have been performed to examine the properties of the tailings. The basic physical and technological characteristics have
been reached. The findings were shown in this paper provide information related to the tailings disposal. The geo-polymerization method of mine tailings of copper has been studied by Fenghua Yang [4], including a chemical reaction method, which can convert alumino-silicate particles or solids into materials having polymer content, by reacting SiO2 and Al2O3 with alkaline solutions. Xu and Deventer [7] studied several mineral geo-polymerizations. For the minerals, e.g. ash, fly, kaolinite and albite, were chosen to experiment in different combinations. The findings revealed that the major-component method, with correct reaction parameters used, gave geo-polymers the greater tensile strength and the lowest cracking likelihood. Geo-polymerization experiments were carried out with low-temperature tuffs (40 °C, 80 °C, 120 °C) in order to build bricks. The average mechanical power was approximately 20 MPa. Torgal. et al [15], tungsten mine waste (950 °C for 2 hours) was used thermally for the preparation of hydration products and the maximum strength was about 80 MPa. Mohsen and Mostafa [11] used low kaolinite clay thermally treated to produce geo-polymer bricks. The alumino-silicate mineral sources, kaolinite clays, were treated pre-thermally for 2 hours at 700 °C. Different temperatures (room temperature, 75 °C and 150 °C) were used for the activation process. The mechanical properties were satisfactory. The reaction between the activation solution and the calcinated clay increases with the increasing temperature from room temperature to 75 °C. Tailing dams height and storage capacity have continuously increased over the past ten to fifteen years to meet the increasing demand for mine operations, which eventually is leading to a higher risk of failure in tailing dams, as stated by Klohn [9], Davis [3] Rico et al. [14]. Many experiments have been done to research about the characteristics (mechanical) of mine tailings and their results vary when Vick, Qiu and Sego [10] checked various kinds of tailings.

3. Methodology

Materials used where mine tailings and kaolin clay.

![Figure 1. Mine Sand](image1)

![Figure 2. Karoline Clay](image2)

The basic properties of the mine sand as well as the kaolinite clay have been shown in Table 1, Table 2 and Table 3. The mine sand (figure 1) was obtained from BCL Mines Selebe Phikwe, South Africa. The kaolinite clay (figure 2) was taken from Sulekha clay factory, Thonnakal in Trivandrum district, Kreala, India. Figure 3 shows the particle size distribution of Mine sand.

| Table 1. Physical properties of Mine Sand |
|-----------------------------------------|
| PROPERTIES       | MINE SAND                        |
| Moisture content | 1.67%                            |
| Specific gravity | 2.72                             |
| Percentage of clay | 0                          |
| Percentage of silt | 0                             |
| Optimum moisture content | 14%                        |
| Maximum dry density | 1.83 g/cm³                        |
| Angle of internal friction | 51°                        |
| Coefficient of permeability | 7.37 x 10⁻⁴ mm/s                  |
Table 2. Chemical properties of mine sand

| CHEMICAL PROPERTIES | MINE SAND   |
|---------------------|-------------|
| pH                  | 4.8         |
| EC                  | 0.129       |
| OC%                 | 1.482       |
| Phosphorous (Kg/ha) | 0.012       |
| Potassium (Kg/ha)   | 123.2       |
| Iron (ppm)          | 183         |
| Zinc (ppm)          | 1.92        |
| Manganese (ppm)     | 7.22        |
| Copper (ppm)        | 3.33        |
| Calcium (ppm)       | 266         |
| Magnesium (ppm)     | 22.75       |
| Sulphur (ppm)       | 18.62       |
| Boron (ppm)         | 0.52        |

Table 3. Physical Properties of Kaolinite Clay

| PROPERTIES                  | KAOLINITE CLAY |
|-----------------------------|----------------|
| Specific Gravity            | 2.64           |
| Liquid limit                | 61%            |
| Plastic limit               | 40%            |
| Plasticity index            | 21%            |
| Shrinkage limit             | 25%            |
| Percentage of clay          | 70%            |
| Percentage of silt          | 30%            |
| Optimum moisture content    | 16%            |
| Maximum dry density         | 1.3g/cc        |
| Unconfined compressive strength | 0.28kg/cm²   |
| California bearing ratio    | 21.3%          |
| USCS Classification         | CH             |

Figure 3. Particle size distribution curve for Mine Sand
4. Result and Discussion

The section summarizes the result obtained from the various tests conducted in the laboratory in order to determine the various properties of mine sand.

4.1 Compaction Characteristics: Compaction characteristics were studied by conducting standard proctor test. The test was carried out on the soil sample to determine optimum moisture content as well as the maximum dry density. The figure 4 shows the compaction curve for the mine sand.

![Compaction Curve for the mine sand](image)

**Figure 4.** Compaction Curve for the mine sand.

4.2 Direct shear test: The importance of internal friction and stability of the soil involved in the design is required for many engineering problems such as foundation design, retention walls, slab bridges, pipes and sheet piling problems. Simple shear tests are used to easily estimate these parameters. Figure 5 shows the stress-strain graph of the mine sand.

![Stress-strain graph of the mine sand](image)

**Figure 5.** Stress-strain graph of the mine sand

4.3 Unconfined compression test: Unconfined compression test (UCC) is the most common and adaptable method of evaluating the strength of stabilized soil. It is the main test recommended for the determination of the required amount of additives to be used in the stabilization of soil. Figure 6 to figure 11 shows the Load-Deformation graph for varying percentage of mine sand ( 2%, 4%, 6%, 8%, 10%, 12%) in kaolinite clay. Table 4 shows the values of UCC with different percentage of mine sand with kaolinite clay.
Figure 6. Load-Deformation graph for 2% mine sand

Figure 7. Load-Deformation graph for 4% mine sand

Figure 8. Load-Deformation graph for 6% mine sand

Figure 9. Load-Deformation graph for 8% mine sand

Figure 10. Load-Deformation graph for 10% mine sand.
The stress-strain graph for different sand content is shown in figure 12. Figure 13 shows the variation of UCC value with different percentage of mine sand.

Figure 12. Stress-Strain curve for varying percentage of mine sand.

Table 4. Variation of UCC value with sand content

| Mine sand content (%) | UCC Value (kg/cm²) |
|-----------------------|--------------------|
| 2%                    | 0.2537             |
| 4%                    | 0.093              |
| 6%                    | 0.2622             |
| 8%                    | 0.296              |
| 10%                   | 0.3477             |
| 12%                   | 0.1500             |
5. Conclusion
This paper evaluated the effect of mine sand which are taken from BCL Mines Selebe Phikwe, on the strength characteristics of kaolinite clay taken from Sulekha clay factory in Trivandrum dist. Different experiments were conducted to determine the properties of mine sand as well as the clay and a series of experiments were conducted with different percentages of mine sand to stabilize the soil.

Based on the experiments conducted the following conclusions are made:

Specific gravity of mine sand is 2.72.
Permeability of sand is $7.37 \times 10^{-4}$ mm/s.
Angle of internal friction is 51

Optimum percentage of mine sand is 10%

Chemical analysis was also conducted and is found that calcium and potassium content predominates. From the studies conducted, we suggest mine sand can be used for stabilization purpose, embankment construction, land filling etc.

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References
[1] Abolfari Shamsai, Ali Pak. (2007). “Geotechnical characteristics of Copper Mine Tailing- A case study.” Geotechnical and Geological Engineering 25, 591-602.
[2] Azam, S., and Li, Q. R. (2010). “Tailings dam failures: A review of the last one hundred years.” Geotechnical News, 28(4), 50–53.
[3] Davis, M. P. (2002). “Tailings impoundment failures: Are geotechnical engineers listening?” Geotechnical News, BiTech Publishers, Richmond, BC, Canada, 31–36.
[4] Fenghua, Yung .(2012). “Geopolymerization of Copper Mine Tailing.” The University of Arizona 1930-1944.
[5] Geremew, A.M., Yanful, E.K.(2012).“Laboratory investigation of the resistance of tailings and natural sediments to cyclic loading.” Geotech. Geol. Eng., 30(2), 431–447.
[6] Geremew, A. M., & Yanful, E. K. (2013). Dynamic properties and influence of clay mineralogy types on the cyclic strength of mine tailings. International Journal of Geomechanics, 13(4), 441-453.
[7] Hua Xu, S J Van Deventer. (2002). “Geopolimerisation of multiple minerals.” Material Engineering, Volume 15 Issue 12, pages 1131-113

[8] James, M., Aubertin, M., Wijewickreme, D., and Ward Wilson, G. (2011). “A laboratory investigation of the dynamic properties of tailings.” Can. Geotech. J., 48(11), 1587–1600.

[9] Klohn, E. J. (1997). “Tailings dams in Canada.” Geotechnical News, BiTech Publishers, Richmond, BC, Canada, 117–123.

[10] Liming Hu, Qingbo Wen. (2017). “Geotechnical Properties of Mine Tailings”, J. Mater. Civ. Eng, 29(2) 04016220

[11] Mohsen, Mostafa. (2010). “Investigating the possibility of utilizing lowKaolinitic clays in production of geopolymer brick.” Ceramic Silikaty, 52(2), 160-168.

[12] Ojuri O.O, Adavi A.A and Oluwatuyi O.E. (2017). “Geotechnical and Environmental Evaluataion of Lime –cement stabilized soil-mine tailing mixtures for Highway Construction.” Transportation Geotechniques, Volume 10, 1-12

[13] Ranno Marlany Rachman Ayi Syaeful Bahri, Yulinah Trihadiningrum.(2018).”Stabilization and solidification of tailings from a traditional gold mine using Portland cement.” Environmental Engineering Research, volume 23(2): 189-194.

[14] Rico et.al (2008). “Reported tailings dam failure : A review of the European incident in the world wide context.” J.Harad Material; 152(2)846-852.

[15] Torgal et.al. (2010). “Durability and Environmental performance of alkali-activated Tungsten Mine Waste Mud mortars.” Journal of Materials in Civil Engineering 22(9) 897-904.

[16] Yazeed Alsharedah and Mohamed H. El Naggar. (2016). “Mining Tailing Stabilization using waste materials.” Resilient Infrastructure London, 1-4

[17] Yunxin Qin, D C Sego. (2001). “Laboratory Properties of Mine Tailings.” Canadian Geotechnical Journal.