Laboratory Study of Stabilization and Solidification of Lead and Zinc Contaminated Soil Using Geopolymer Cement

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ABSTRACT

This research investigates the capabilities of geopolymer cement in the stabilization and solidification of heavy metal-contaminated soils, particularly those contaminated with lead and zinc. One of the key aspects of this research is the use of steel and blast furnace slags, considered as industrial waste, as raw materials in the production of geopolymer cement. To this end, contaminated soil samples were stabilized using both types of binders, and various tests, including compaction, uniaxial compressive strength (UCS), toxicity characteristic leaching procedure (TCLP), and scanning electron microscopy (SEM), were conducted to evaluate the performance of the binders. The results of the uniaxial compressive strength tests showed that the samples stabilized with geopolymer cement exhibited higher strength at all curing times compared to those stabilized with Portland cement, with a strength increase of approximately 100 to 200 kPa. Moreover, the leaching test results indicated that steel slag significantly reduced the concentration of lead ions from 26,000 ppm to less than 1 ppm. In the case of zinc, the concentration was reduced from 16,000 ppm to 0.3 ppm, demonstrating the high potential of this material in the stabilization of heavy metals. However, despite the high compressive strength of sodium silicate-containing samples, they were less effective in reducing the concentrations of heavy metals in the leaching tests. This research also showed that increasing the binder content improved the mechanical strength of the samples and enhanced the stabilization of contaminants.

KEYWORDS

Geopolymer cement, Soil stabilization, Leaching, Lead and Zinc, Compressive strength

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1. Introduction

Various technologies have been developed to transform hazardous wastes into non-toxic materials or reduce the potential release of toxic species into the environment. Examples include chemical precipitation, electrolysis, biological treatment, and stabilization/solidification (S/S) [1]. Remediation technologies can be classified based on in situ or ex situ immobilization or extraction (the action applied to metals) and other types of technologies. Remediation of heavy metal contaminated soils is limited to two main strategies: immobilization and extraction [2]. Generally, stabilization is a process in which additives are mixed with waste to minimize the rate of movement of contaminants from the waste and reduce the toxicity of the waste. Therefore, stabilization can be described as a process in which contaminants are completely or partially confined by the addition of supporting agents, binders, or other modifiers. Similarly, solidification is a process that uses additives to change the physical nature of the waste (measured by engineering properties such as strength, compressibility, or permeability) during the process. Therefore, the goals of stabilization and solidification include both reducing the toxicity and mobility of the waste and improving the engineering properties of the stabilized material [3]. The S/S method is considered to be one of the effective methods for removing heavy metal contamination from contaminated soils. This method has high efficiency and can reduce the leaching of hazardous substances from waste disposed of in landfills and contaminated soils [4]. In the S/S method, various materials are used as binders, the most common and widely used of which is ordinary Portland cement. Other materials that can be used as binders include lime, gypsum, pozzolans, and fly ash. In some cases, several stabilizing agents are used in combination and the effect of each of these materials on stabilization is studied [5]. Usually, ordinary Portland cement is used for the S/S method; however, the degree of reduction in the strength of cement-contaminated soils depends strongly on the type and concentration of heavy metals. On the other hand, considering the environmental challenges associated with the production of Portland cement, including high carbon dioxide emissions and high energy consumption, the need to find sustainable and environmentally friendly alternatives is essential. In this regard, geopolymer cement has been proposed as a suitable alternative due to its high potential in reducing environmental impacts, significant mechanical properties, and resistance to corrosive conditions [6].

Geopolymer cement, which is known as a new type of adhesive, is a type of inorganic cement obtained by combining aluminosilicate raw materials with alkaline solutions.

Considering other studies conducted on the use of geopolymer cements for the removal of heavy metals from soil, the main objective of this study is to compare the performance of geopolymer cement with two separate types of slags, iron and steel smelting, as well as ordinary Portland cement as a binder. In this study, two types of alkaline solutions, including sodium hydroxide and sodium metasilicate, were used in different ratios to activate the slag. Also, the efficiency of these compounds in controlling the release of metal ions and the effect of curing conditions and time on the mechanical strength of the samples and the stabilization of contaminants were evaluated.

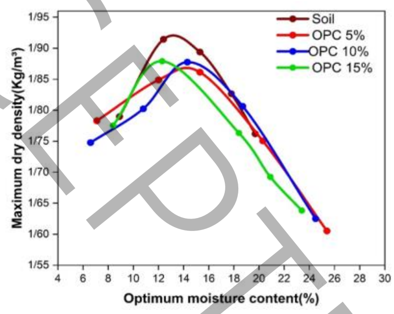
2. Methodology

In this study, a contaminated soil sample from a lead and zinc mine waste site located in Buin Zahra County was used. Due to mining activities, this area contains significant amounts of mineral waste that have been improperly disposed of in a landfill. Improper accumulation of this waste has increased the risk of heavy metal contamination in the surrounding soils and has become a potential source of environmental pollution. To investigate this issue in detail, completely random sampling was carried out from different parts of this site. Two separate types of slag were used to produce geopolymer cement in this study: iron smelting slag and steel slag. For sample preparation the soil, slag and cement were dried in an oven for 24 hours at 110 degrees Celsius to ensure that no moisture remained in the materials. This step was necessary to accurately control the moisture content of the samples, as residual moisture could change the results. The alkaline solution was also prepared one day before the samples were prepared. This was done because the alkaline solution generates heat during production and there must be enough time to reduce this heat so that it does not affect the final properties of the samples when mixed with other materials. To investigate the effect of curing time on the properties of the samples, four different time periods were considered, including 3, 7, 28 and 90 days.

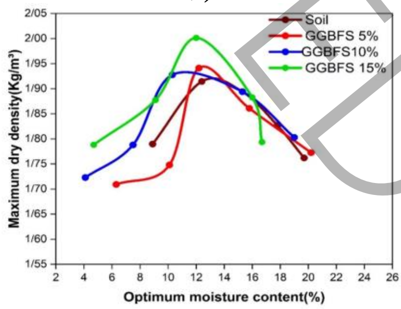
3. Discussion and Results

The graphs related to the compaction test are shown in Figure 1. The results indicate that the addition of cement, iron smelting slag and steel have different effects on compaction parameters. These changes are clearly observed in the graphs of optimum moisture content and dry specific gravity. The soil compaction graphs show significant differences in the mechanical behavior of soil with the use of different additives.

Adding cement to the soil increased the optimum moisture content. This increase may be due to the water absorption characteristics of cement and the need for more moisture for better compaction. However, the addition of cement led to a decrease in the dry specific gravity. This decrease may be due to the change in the internal structure of soil and cement and its effect on soil compaction.



a)



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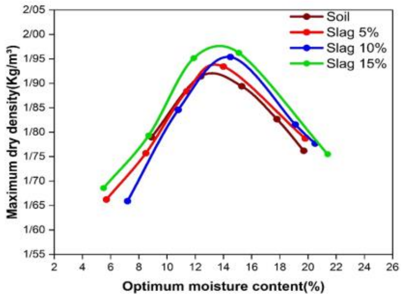

c)

Figure 1: Compaction of contaminated soil a) mixed with cement b) mixed with GGBFS c) mixed with slag

According to the standards of the Environmental Protection Agency (EPA), all industrial and mining waste accumulations must be monitored for heavy metal concentrations by leakage tests (TCLP). The TCLP test simulates acid rain conditions over a long period of time (approximately 100 years). This test uses a weak acidic solution (usually acetic acid) to model the long-term effects of acid rain on the samples and measures the amount of pollutants that may be released from the samples during this period. The results of this test can help determine the long-term stability and safety of stabilizing materials in the face of environmental conditions. EPA Method 1311 was used to conduct a deep leaching test of mineral tailings and to evaluate the potential for heavy metal release from stabilized samples after 28 days of curing. The TCLP test results (Figure 2) showed that steel slag effectively prevented the leakage of pollutants, and the levels of pollutants were within the desired range and below the established standards. Portland cement also performed similarly and prevented the leakage of pollutants well. However, iron and steel slag performed worse than the other two options, and the amount of leaked pollutants was higher than the standard limit.

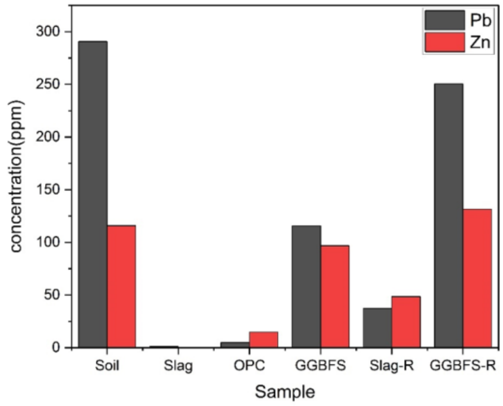

Figure 2: Concentration of heavy metals extracted from TCLP test

4. Conclusions

The results of the tests showed that the addition of cement caused a slight increase in the optimal moisture content but a decrease in the maximum dry specific gravity. These changes indicate that cement, due to its nature, requires more water to achieve optimal compaction, but at the same time, it makes the soil structure less dense. In the case of iron smelting slag, the increase in specific gravity and optimum moisture content indicates that this material contributes to greater soil compaction and requires more water to achieve optimum compaction. In general, these results indicate that each material has different effects on soil compact ability and optimum moisture content due to its physical and chemical properties. The results of this study show that geopolymer cement shows higher initial strength compared to Portland cement and can be a suitable option for situations where there is a need for rapid stabilization of soil contamination.

5. References

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