Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 55(4) (2023) 155-158
DOI: 10.22060/ceej.2023.21527.7753

# Efficiency of various binders in solidification/stabilization of heavy metals and compressive strength in sludge of Ceramic tile factory Niloufar in Birjand

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**ABSTRACT:** Solidification/stabilization (S/S) is a common process in the treatment of sludge containing heavy metals. In this study, S/S of ceramic tile industry sludge was investigated using cement and additives like water, lime, microsilica, and clay. By response surface methodology, the effect of different additives on compressive strength and metals concentration after the pollution leakage test was evaluated. Results showed the highest compressive strength in high amounts of cement. Decreasing the waste and replacing more lime, clay, and microsilica, the compressive strength increased. Under obtained optimum conditions, by 5.77% lime, 8.69% clay, 4.35% microsilica, and 51.84% cement, the maximum compressive strength was achieved at about 116 kg/cm2. The minimum concentration of Cr was 0.0782 mg/L and resulted from 11.23% lime, 21.31% clay, 10.65% microsilica and 27.46% cement. Minimum Pb concentration (0.0043 mg/L) was obtained in 11.23% lime, 21.31% clay, 4.35% microsilica and 33.76% cement. The more efficiency in compressive strength is related to cement. In addition, applying the binders concluded the effective reduction of Cr and Pb concentration in leaching the stabilized samples.

**Review History:**

Received: Jun. 26, 2022
Revised: Dec. 28, 2022
Accepted: Jan. 01, 2023
Available Online: Jan. 10, 2023

**Keywords:**

Solidification/stabilization
Chromium
Lead
Portland cement
Industrial Sludge
RSM

## 1- Introduction

Heavy metals are among the most common pollutants that are usually found in high concentrations in industrial wastewater and cause damage to aquatic environments and endanger the health of living organisms, especially humans. The most important heavy metals in terms of production and pollution are Pb, Cr, As, Zn, Cd, and Hg [1]. Cement stabilization and solidification is one of the most widely used methods to treat hazardous wastes, due to its simplicity and low cost [2]. The main goal of this process is to reduce the transport of various pollutants from inside the landfill to natural environments [3]. Cement is one of the widely used binders in S/S process [4, 5]. In this method, the mobility and toxicity of inorganic compounds are decreased by the creation of insoluble hydroxides, the transfer of heavy metals to mineral structures, and the physical confinement of compounds [6, 7]. The wastes are combined with binders such as cement, pozzolan, lime, and geopolymer, then fixed and locked. The result of the study on the Nilufar tile and ceramic factory (Birjand) sludge is indicating the presence of heavy metals as Cr and Pb. Releasing this sludge into the environment leads to the pollution of the environment (groundwater). In this research, the S/S of Cr and Pb in the sludge of the above factory has been investigated by applying cement and additives (lime, microsilica, and ordinary clay). Also, the effect of cement, water, lime, microsilica, and clay on the system performance and efficiency has been evaluated. For this purpose, in order to achieve the highest rate of efficiency with the least number of tests, process optimization has been conducted using the response surface methodology (RSM).

## 2- Materials and Methods

In this research, the waste of the Nilufar tile and ceramic factory (Birjand) was used. Cement type II was selected due to its availability and wide application in S/S [1, 8]. Lime was applied as neutralizing and stabilizing agent, because of high alkalinity. Applying lime leads to more increase of acidic sludge pH than applying the cement and pozzolan; thus better stabilization is resulted. Mocrosilica was used to improve the cement hydration reactions. Used clay, kaolinite by pH=5-6, was provided by Iran China Clay Company. In addition, the water was distilled water without any solutes and metals by pH=6-7. To determine the test conditions, the Central Composite Design (CCD) as a subset of RSM was employed (Design Expert 7.0.1 software). By RSM a continuous statistical model is created which is effective in the determination of the optimal conditions with high accuracy and reliability [9]. In continuing, by referring to other studies and conducting some pretests, the levels of independent variables were determined [10, 11]. The variables affecting the S/S process include lime, clay, microsilica, water, and

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**Table 1. Parameters and related levels for optimization of S/S process**

| Material (%) | Level | | | |
|---|---|---|---|---|
| | -1 | +1 | -α | +α |
| lime | 5.76709 | 11.2329 | 2 | 15 |
| clay | 8.69323 | 21.3067 | 0 | 30 |
| microsilica | 4.34664 | 10.6534 | 0 | 15 |
| water | 45.7955 | 54.2045 | 40 | 60 |
| waste | 29.3466 | 35.6534 | 25 | 40 |

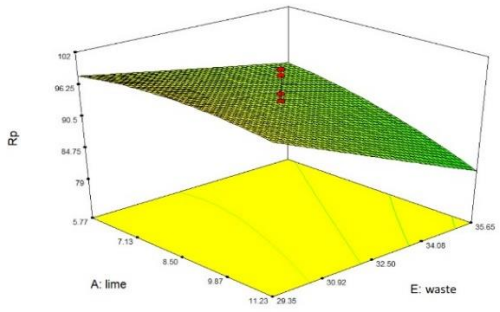
waste. The examined levels of each are given in Table (1). Cr concentration, Pb concentration, and compressive strength were considered as responses. After performing 50 experiments designed by the software (having 5 repetitions at the central point), the optimal conditions were determined. Then, to validate the obtained model, a confirmation test was performed and the optimal test was repeated in the desired conditions. To make the samples, the mortar was put into 50 mm cube-shaped molds (ASTM C109-90 standard). After initial setting in 24 hours, the samples were placed in water for 28 days. In the compressive strength test, the samples are broken by a hydraulic press machine. The results show the endurance of the stabilized materials against the environmental loads of the landfills [9]. In this method, the amount of compressive strength was calculated in $kg/cm^2$ (ASTMC109-80 standard). The test of Toxicity Characteristic Leaching Procedure (TCLP) is one of the most important tests for leaching hazardous wastes, used in many researches related to the S/S. Using that, it is possible to investigate the separation amount of heavy metals from the stabilized material under natural conditions in landfills. In this method, the amount of metals in the leachate was measured with the Flame Atomic Absorption Spectrometry (FAAS).

## 3- Results and Discussion

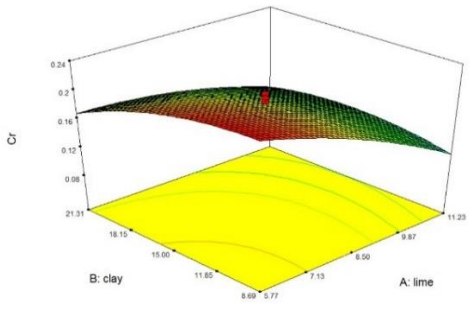
After conducting the experiments according to the experimental design, the compressive strength of all samples was obtained more than the minimum value based on EPA (3.5 $kg/cm^2$). The sample with the lowest amount of lime, clay, microsilica, and waste and, consequently, the highest amount of cement, has the highest compressive strength. The mixing plan of that included lime 77.5%, clay 8.69%, microsilica 4.35%, water 45.8%, waste 29.35%, and cement 51.84%. So, the greatest effect of binders is related to cement. The TCLP results of all samples were less than the allowed concentration of heavy metal in the extraction solution. Figure (1) shows the simultaneous effect of different binders on the compressive strength and the concentration of Cr and Pb. According to Figure (1-a), the reduction of lime and an increase in waste has caused, respectively, an increase and a decrease in compressive strength. In other words, with increasing the waste and lime the compressive strength of the samples has decreased, due to the decrease in cement. Figure (1-b) shows the effect of lime and clay and Figure (1-c) shows the effect of lime and microsilica on Cr leaching. As can be seen, with the increase of these binders, the Cr concentration has decreased. The increase in lime caused an increase in pH, and then, caused a decrease in Cr leaching. According to Figure (1-d), it is clear that an increase in lime and clay decreased Pb leaching. In addition, from the figure (1-e) it can be concluded that the increase of lime and microsilica both cause the same result.

## 4- Conclusions

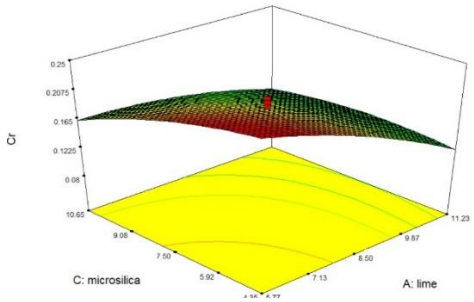
Based on the conducting tests in this research, by using the cement and lime, microsilica, and ordinary clay additives in the S/S of sludge, the compressive strength and concentration of metals after TCLP were evaluated. This result was obtained that among the binders, cement has the greatest impact on the compressive strength, directly. While, the increase of lime, clay, and microsilica has reduced the compressive strength. The results of TCLP indicate that the increase of cement had a low effect on the leaching of Cr and reduced that. Also, the increase of lime and clay has resulted in the reduction of pollutant leaching; while the increase of microsilica caused the increase of pollutant leaching. The concentration of Pb in the TCLP test was close to zero.



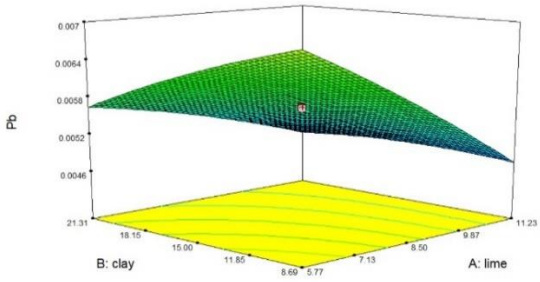

(a) Effect of lime and waste on compressive strength



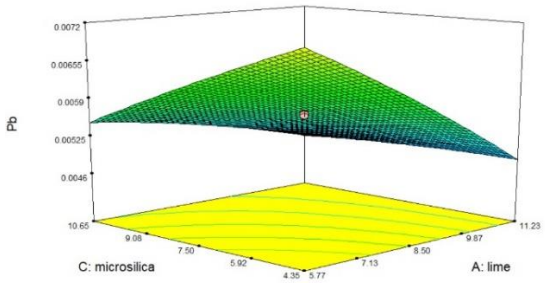

(b) Effect of lime and clay on Cr concentration




(c) Effect of lime and microsilica on Cr concentration




(d) Effect of lime and clay on Pb concentration




(e) Effect of lime and microsilica on Pb concentration

**Fig. 1. Effect of different binders interaction on compressive strength and metals concentration**

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**HOW TO CITE THIS ARTICLE**

*MJ. Zoqi, M. Ayobi, B. Khataei, Efficiency of various binders in solidification/stabilization of heavy metals and compressive strength in sludge of Ceramic tile factory Niloufar in Birjand, Amirkabir J. Civil Eng., 55(4) (2023) 155-158.*

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