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Use of electroplating sludge in production of fired clay bricks: Characterization and environmental risk evaluation

Minte Zhang [a], Chen Chen [a], Linqiang Mao [b,*], Qing Wu [a,*]

[a] School of Architecture and Civil Engineering, Jiangsu University of Science and Technology, Zhenjiang 212005, PR China
[b] School of Environmental and Safety Engineering, Changzhou University, Changzhou 213164, PR China

HIGHLIGHTS

- Introduction of electroplating sludge decreases compressive strength of bricks.
- Prepared bricks have enough strength required by standard.
- Optimum amount of electroplating sludge in clay bricks was less than 8 wt%.
- Leachability of heavy metals from bricks met regulation limit standard.

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ABSTRACT

A noticeable amount of electroplating sludge, resulting from electroplating and surface treatment industries, may pose serious threat to human health and surrounding environmental without safe treatment. This study examined the feasibility of preparing the fired clay bricks with the addition of electroplating sludge, by evaluating the physical properties and environmental risk of the prepared clay bricks. It was found that the introduction of electroplating sludge reduced the bulk density and compressive strength, and increased the mass loss, linear shrinkage, porosity ratio and water absorption. It was observed compressive strength declined from 23.5 to 15.5 MPa, and water absorption increased from 2.7 to 3.46% with the addition of electroplating sludge up to 10 wt%. Though the introduction of electroplating sludge influenced the mechanical and physical properties, these parameters are enough according to the values required by the standards. Prolonged leaching experiments up to 20 days were carried out to test the whole bricks and brick powder. The results clearly presented the optimum substitution amount of electroplating sludge in clay bricks was less than 8 wt%. Besides, leaching test suggested that though the prepared bricks with the addition of electroplating sludge were abandoned in the surrounding environmental after the use period, the leaching risks of heavy metals released from the bricks still can be reduced substantially, because heavy metals might be incorporated into stable mineral structure during firing process. These results suggested use of electroplating sludge in the production of fired clay bricks or ceramics might be a alternative and reliable method for the disposal of electroplating sludge.

1. Introduction

The rapid development of electroplating industries usually produce a noticeable amount of electroplating effluent, which needs a series of treatments in order to meet the environmental requirements before being discharged out of the plant [1]. A large amount of sludge is thereby produced by the physic-chemical treatment of wastewater generated in electroplating plants [1,2]. This sludge usually contains a noticeable amount of heavy metals, colloid aluminium hydroxide, aluminium sulphate (used as a flocculating agent), sodium and calcium ions (generated in neutralizing solutions) and water [3]. The highly complex components in electroplating sludge pose serious threat to human health and surrounding environment [4], the disposal of electroplating sludge is therefore always a pressing environmental problem for electroplating industry and environmental engineering.

The most common way to dispose of electroplating sludge is landfill deposition. However, the deposition of electroplating sludge in landfill is not a very environmentally friendly alternative. Hydrometallurgical technologies, such as chemical precipitation [5], electrochemical reduction [6], ion exchange [7], adsorption

* Corresponding authors.
E-mail address: maolinqiang2008@126.com (L. Mao).

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[8], and membrane processes [9] can be applied in the recovery of the valuable metals from electroplating sludge. There are important research works on the extraction and the reuse of heavy metals (Ni, Zn, Cu, etc.) extracted from electroplating sludge [5–9]. Though these developed technologies are advanced and effective for the recovery of heavy metals, these methods for reuse developed so far do not consume electroplating sludge in large quantities. Many researchers have attempted to immobilize electroplating sludge using sorbents or cements [10,11]. However, solidification/stabilization technologies by sorption or cementation methods may not be successful in the prevention of metal leaching in acidic environments [11].

The building industry, which usually involves huge amounts of resources, is at the forefront on the reutilization of solid wastes. In particular, manufacturing of clay bricks and Portland cement plays an ever more important role in the management of hazardous wastes from different industrial sectors [10]. Many authors have studied the utilization of industrial waste materials as additive of clay bricks and cement [12–18]. Some different inorganic waste materials such as ferrochromium [12], pumice [15], marble [16], waste glass [17], and construction and demolition waste [18] have been used. Such wastes have substituted for raw materials and their subsequent stabilization in matrix or mortar makes a significant environmental contribution. Besides, this integrated activity offers additional revenues to the brick and cement industry as the disposal of wastes normally receives a financial incentive.

The reaction behaviour of hazardous metals in the manufacturing clay and cement is a fundamental parameter for the evaluation of benefits and risks for the substitution of electroplating sludge. Some studies have reported Cr(III) would be oxidized into carcinogenic Cr(VI) due to the presence of free CaO, during the thermal process of some solid waste containing chromium, such as municipal waste incineration fly ash [19], tannery sludge [20] and electroplating sludge [21]. For example, Sinyoung et al. [22] have investigated the chromium behaviour during use of electroplating sludge in the production process of cement, some new Cr(VI) phases in the clinker was detected and the leaching concentration of Cr(VI) was higher than regulation limits. Thus, use of electroplating sludge containing chromium in the production of cement should be treated with caution. Unlike the cement production, there is no lime addition during the production process of fired clay bricks and the oxidation of Cr(III) to Cr(VI) would be suppressed effectively. The bricks or ceramics industry is therefore the best candidate to consume large amounts of electroplating sludge. The fried bricks and ceramics are the materials best suited for achieving the inertization and neutralization of electroplating sludge by encapsulating it in the matrix [23,24].

The aim of current work is to examine the feasibility of using electroplating sludge to substitute raw material in the production of fired clay bricks, and the change in physical and mechanical properties of the prepared clay bricks. Additionally, the leaching risk of heavy metals from the fired clay bricks was evaluated for determining the environmental safety. The optimum ratios of substitution for satisfying technical requirement and environmental criteria were also determined.

2. Materials and methods

2.1. Materials

The electroplating sludge used in this study was collected from the electroplating industry located in Changzhou city, Jiangsu province. This collected sludge was dried at 105 °C for 24 h, and crushed to powder with a particle size suitable to pass through a 74 μm sieve (200 mesh). The clay raw material was obtained from a brick manufacturer in Changzhou city, Jiangsu province. The chemical compositions of electroplating sludge and the clay were determined by the X-ray fluorescence (XRF) elemental analysis spectrometer. The crystalline phase of the raw materials was analyzed by the X-ray powder diffraction (XRD), and their thermal behaviours were performed by Different Scanning calorimetry (DSC). The particle size distribution of raw materials was measured with a Laser Particle Size Analyzer. Approximate 1.0 g of samples were suspended in 100 mL deionized water and the suspension used for analysis. The morphology of fired samples was observed by Scanning Electron Microscope (SEM) and element analysis of specific areas of samples with EDS analysis attached in SEM.

2.2. Processing method

The electroplating sludge was added to the received clay in different contents (0, 2, 4, 6, 8, 10%), and the mixtures was milled in a ball mill for 30 min to obtain good homogenization. Ten samples per series were prepared for testing. The necessary amount of water (about 10 wt% of raw materials) was added to the samples to obtain adequate plasticity and absence of defects, mainly cracks, during the semi-dry compression moulding stage under 40 MPa of pressure, using a laboratory-scale pressure machine. Solid bricks with 50 mm × 35 mm × 10 mm were prepared with shape process. The prepared raw bricks were dried in and oven at 110 °C for 24 h. The dry samples were then fired in a laboratory-type electrical furnace at a rate of 5 °C/min to 950 °C for 3 h, and then the fired samples were then cooled to room temperature.

2.3. Properties of fired samples

In this study, liner shrinkage, mass loss ignition, bulk density, water absorption, open porosity and compressive strength of the fired bricks were performed for evaluating whether the resulting fired bricks samples fulfilled the building standards. The linear shrinkage (%) was determined from the length of the samples before and after firing using a calliper with a precision of ±0.01 mm. The mass loss on ignition was determined as the mass loss between drying at 110 °C and firing at 950 °C. It is expressed as a percentage. The bulk density (g/cm^3) of the fired bricks was determined as the ratio of the dry mass of the fired sample and its volume, being determined according to a standard method [25]. Water absorption capacity (%) was determined according to the standard procedure [26] using dried samples (110 °C for 24 h) and weighed repeatedly until the mass difference was 1%. The samples were completely immersed into water for 24 h, then the samples were dried with a damp cloth and weighted again. The ratio of the increment weight to the dried samples was identified as water absorption. Open porosity (in vol.%) was calculated from the weight difference between saturated mass and dry mass with respect to exterior volume and closed porosity was determined from weight difference between dry mass and suspended mass in water with respect to exterior volume according to ISO 10545-3:1995 [26]. The compressive strength was measured for fired samples according to the standard procedure in a laboratory testing equipment. All shaped samples were tested by applying the load centred on the upper face of the brick with a speed 20 MPa/s until fracture. For this trial, five fired samples were tested.

2.4. Leachability of fired bricks

Solid waste-Extraction procedure for leaching toxicity-Acetic acid buffer solution method [27] was employed to evaluate the leachability of heavy metals for determining if they were immobilized into the clay matrix. To better evaluate the immobilization efficiency of heavy metals in fired clay bricks, both whole fired brick and the powder resulted from grinding fired bricks were subjected to a leaching test in which the leaching time was prolonged to 20 days. For the whole bricks, the weight of every brick block was about 35 g and the whole fired brick was steeped in sealed polyethylene bottles containing the leaching solution of 700 mL (L/S = 20). For the fired brick powder, a leaching vial was filled with 10 mL of acetic acid solution and 0.5 g of fired brick powder (L/S = 20) and it was rotated end-over-end at 60 rpm for same agitation periods. At the end of each agitation period, the leachates were filtered through a membrane (0.2 μm) and the concentration of heavy metals in leachates were determined by flame atomic absorption spectrophotometer. In all leaching tests, a pH 2.9 acetic acid solution was used as the leaching fluid, and it was prepared by diluting 17.25 mL acetic acid to 1 L with deionized water.

3. Results and discussion

3.1. Characterization of raw materials

The chemical composition of the raw materials is given in Table 1 in oxide form. The composition of the clay used in this study was similar to that of typical clays used in industrial brick manufacturing with Si, Al Ca, Fe as the main components. Electroplating sludge was collected from the electroplating factory and the heavy metals, such as Zn, Cr, Ni and Cu, were the main pollutants present in this sludge. This electroplating sludge contained