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Technical note

Addition of waste glass for improving the immobilization of heavy metals during the use of electroplating sludge in the production of clay bricks

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HIGHLIGHTS

- Waste glass addition reduces open porosity and surface area of bricks.
- Waste glass addition improves compressive strength of bricks.
- Brick matrix becomes more dense because glass phase filled in pores.
- Waste glass addition reduces the leachability of heavy metals significantly.

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ABSTRACT

A novel strategy for improving the immobilization of heavy metals during the use of electroplating sludge in the production of clay bricks, was proposed by the addition of waste glass. Waste glass addition reduced open porosity and surface area, and enhanced compressive strength remarkably. With the adding amount of waste glass powder up to 30 wt.%, surface area and open porosity declined from 0.84 to 0.05 m^2/g and from 10.69 to 1.16%, respectively. Compressive strength increased from 20 to 32.7 MPa. Moreover, the leaching concentration of heavy metals decreased considerably and met the regulation standard. Heavy metals, Cu and Zn, have been incorporated into stable spinels phase and adding waste glass was favored to the formation of spinel. It was regarded that waste glass and andesine melted and formed liquid phase during firing process, which improved the mass transfer and the reaction kinetic of spinels formation. The liquid phase filled in the pores and densified bricks body, which also play a important role in preventing heavy metals from releasing. Overall results suggested the addition of waste glass powder was a promising method in improving immobilization of heavy metals during the use of electroplating sludge in production of clay bricks.

1. Introduction

The rapid development of electroplating industries have produced a great deal of electroplating sludge, which may pose serious threat to human health and required special treatment prior to the landfill, because this sludge usually contains a noticeable amount of heavy metals. Solidification/stabilization technologies by cementation were widely adopted approaches of eliminating the hazards of heavy metals. However, the volume of cement solidification matrix increases considerably comparing with electroplating sludge, which enhances the burden of the landfill [1].

The substitution of electroplating sludge in the production of clay bricks has been successfully pursued since it can reduce both the consumption of natural resources and the cost of waste disposal [2]. For example, Pérez-Villarejo et al. [3] have investigated the potential for the use of electroplating sludge in the production of clay bricks. The leachability of heavy metals from the brick matrix was reduced substantially, the maximum addition amount was around 5 wt.%. While the leachability of heavy metals exceeded the regulation value with addition amount over 5 wt% [3]. The interaction of heavy metals with silicon, aluminum and ferric resulting in the mineralization, were largely responsible for the decreasing leachability of heavy metals from the bricks matrix [4]. However, the reduction in the porosity and specific surface area of fired bricks after firing process, also makes more contribution to preventing of heavy metals releasing. Therefore, decreasing

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the porosity and specific surface area of fired bricks might improve the immobilization of heavy metals. It is necessary to densify the bricks body for decreasing the porosity and specific surface area. The vitrification of the raw bricks by melting may be a good alternative, but vitrification was usually carried out above 1300°C [3]. Thus a traditional glass-forming technique may not be applied.

Waste glass powder would melt at relative low temperature and produce some liquid phase [5]. It is assumed that the formed liquid phase filled in the porosity and coat the surface of bricks matrix, the porosity and specific surface area of fired bricks would be decreased considerably, benefiting to prevent heavy metals from releasing. To verify this hypothesis, in this study, waste glass powder was employed to fill in porosity and densify bricks body for examining its influence on enhancing the immobilization of heavy metals.

2. Materials and methods

The electroplating sludge and clay were collected from the electroplating industry and a brick manufacturer respectively located in Changhzou city, Jiangsu Province. Waste glass powder was obtained from milling broken glass bottles with ball crusher. All raw materials were dried at 105 °C for 24 h and pass through a 74 μm sieve (200 mesh) for a homogeneous particle size. The chemical compositions of raw materials were analyzed by X-ray Fluorescence and results were shown in Table 1.

Higher content of electroplating sludge of 10 wt% was added in raw bricks for reflecting the increase in the immobilization of heavy metals due to the substitution of waste glass. Different contents (5, 10 15, 20, 25, 30 wt%) of waste glass powder were added, the mixtures was milled in a ball mill for 300 min to obtain good homogenization. Solid bricks with 50 mm × 35 mm × 10 mm were prepared with shape process under 40 MPa of pressure. 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 [6].

The water absorption capacity, open porosity and compressive strength were measured according to the standard procedure (GB5101-2003). The morphology of samples was analyzed with Scanning Electron Microscopy(SEM). The crystalline phase of the raw materials was analyzed by the X-ray powder diffraction (XRD). The surface area of bricks was detected by a N_2 absorption apparatus, adsorption-desorption isotherms of N_2 at 77 K after outgassing for 2 h at 150 °C, the BET surface area was calculated in a Micrometritics equipment, following the BJH method [7]. Toxicity Characteristic Leaching Procedure (HJ/T 300-2007) was used to evaluate the immobilization of heavy metals after firing process, 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), and it was rotated end-over-end at 60 rpm for same agitation periods. At the end of 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 [8].

Table 1
XRF analysis results of clay, electroplating sludge and waste glass powder.

Oxide content (%)	Clay	Electroplating sludge	Waste glass powder
SiO_2	56.19	1.24	70.49
Al_2O_3	19.93	0.35	0.35
Fe_2O_3	6.02	27.54	2.80
K_2O	2.69	0.12	0.21
CaO	2.29	2.65	4.10
MgO	1.93	0.24	1.56
TiO_2	0.78	0.02	0.15
Na_2O	0.52	3.15	20.30
MnO	0.09	0.13	nd[b]
P	0.06	1.47	0.03
S	0.04	0.29	nd
Cr_2O_3	0.02	nd	nd
ZnO	0.16	14.24	nd
CuO	nd	11.18	nd
Cl	0.01	2.80	nd
LOI[a]	9.267	34.54	nd

[a] : Loss on ignition at 900 °C.
[b] : not detected.

3. Results and discussion

Table 1 presented Zn and Cu were main hazardous pollutants in the electroplating sludge, they were also the common heavy metals presented in electroplating sludge. The mass fraction of SiO_2 in clay and waste glass powder accounted for 56.19 and 70.49%, respectively. The mass fraction of Na and Ca oxides are 3.15 and 2.65 wt%, respectively. Which was lower than other sludge obtained by lime neutralization and precipitation process, and this sludge might be obtained by adding chemical complexing agent into effluent. Additionally, the loss on ignition at 900 °C of clay and electroplating sludge were 9.26 and 34.54 wt%, respectively. The main composition of waste glass used in this study was SiO_2 and accounted for 70.49 wt%, and no hazardous metals were detected.

Water absorption is an important factor for the durability of clay bricks [9]. Fig. 1(a) showed both water absorption and open porosity declined with the increase in the addition of waste glass powder. With the adding content of waste glass powder up to 30 wt.%, water absorption declined from 7.64 to 2.74%, and open porosity decreased from 10.69 to 1.16%. It implied that the number of pores decreased due to the addition of waste glass powder, which effectively prevented the leaching solution intruding into bricks body and was favored to improve the immobilization of heavy metals [10]. Additionally, the number of pores in clay body dropping greatly means a decrease in surface area of bricks body. Fig. 1(b) depicted that BET surface area of bricks declined remarkably from 0.84 to 0.05 m^2/g with the adding amount of waste glass powder up to 30 wt.%. It was means that the contact area between heavy metals and leaching solution would be cut down with the addition of waste glass powder. SEM images in Fig. 2 showed the fractures of bricks with various amount of waste glass powder addition. It was observed that the quantity of pores reduced significantly and the bricks matrix became more dense and homogeneous with the increase in waste glass contents, which was agreed with the change in water absorption, open porosity and surface area. These observations confirmed our assumption in which waste glass powder would fill in the pores at high process and densify bricks matrix. Open porosity, water absorption and surface area of bricks are closely depended on the adding amount of waste glass [10], and increasing waste glass addition was benefit to the reduction in open porosity and surface area of bricks. The addition of waste glass would produce liquid phase during firing process, these liquid phase might close the internal pores and reduce the numbers and size of pores in fired brick body substantially [11,12].

Fig. 3 presented the compressive strength of fired bricks, the compressive strength increased with the introduction of waste glass powder. According to the standard test (GB/T 2542, Chinese standard), compressive strength of fired bricks must be higher than 10 MPa, the compressive strength of all prepared bricks in this study met regulation requirements. It is believed compressive strength is closely related with the porosity of bricks body, and