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Application of dry composite electroplating sludge into preparation of cement-based decorative mortar as green pigment

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ABSTRACT

The objectives of this study were to assess the feasibility of application of dry composite electroplating sludge (CEPS) into preparation of cement-based decorative mortar as green pigment, and to find a new disposal and resource approach for it. Color, water absorption, strength, hydration and leachability of cement-based decorative mortar are investigated. The results show that CEPS can adjust the mortar color well. Although CEPS leads to the increase of mortar water absorption, the water absorption of mortar prepared with 5% CEPS still meets the requirement stated in the Chinese Building Material Industry Standard JC/T 1024-2007. The mortars with CEPS are provided with nearly same compressive, flexural and tensile bond strengths as these of the control. Cement hydration products such as C–S–H gel, $Ca(OH)_2$ and the entringite all can be observed in different specimens. The denser microstructures than that of the control are formed in the mortars with CEPS. It is found from almost similar intensity in $Ca(OH)_2$ peak at 18.007° that CEPS has not notably influence on the cement hydration. It is also evident that heavy metal concentrations in leachates of the mortars with CEPS are far lower than recommended in the Chinese National Standard GB5085.3-2007. It is safe to people's health and environment that CEPS is recycled as green pigment to produce cement-based decorative mortar.

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1. Introduction

The increasing industrial development induced by a constant demand for products has resulted in an exponential growth of waste generated at the end of the manufacturing processes as well as post-consumer disposal. These wastes generally are harmful to people's health, ecology and environment. Discharges of untreated these wastes are the most important cause of environmental pollution in developing countries, especially in China and India. But if it is disposed with the rational technology or approach, it may be changed valuable resource or energy. Public health and environment will be prevented from their potential threat, and the resource, ecology and sustainable is practical, whilst people can be engaged and empowered better. The reasonable disposal opportunities for these wastes consequently have been the expectance, which the enterprise, researcher and government have given their great efforts to realize.

Electroplating industry produces a large quantity of waste sludge, which commonly contains many metallic elements such as Fe, Al, Mg, Cu, Cr, Pb, Ni and Zn. It is the hazardous waste because these toxic heavy metals such as Cu, Cr, Pb, Ni and Zn are serious threats to the environment and ecology if it is improperly treated. Land treatment is the main selection for its disposal. Cement, binder and additive are generally used in order to improve the long-term stability, and reduce the heavy metal leach (Asavapisit Chotklang, 2004; Qian et al., 2009). Unfortunately, insufficient immobilized ability of landfill still may lead to the heavy metal leach, and contaminate soil and underground water. High cost which comes from the limited availability of sites is other concern. What is more important is that this common treatment will waste the valuable resource. In China alone, more than 100,000 t of valuable heavy metals in the form of electroplating sludge (EPS) are wasted every year. In order to have both sound environment protection and sustainable development that highly emphasizes resources reuses, it is of great importance to find a reasonable disposal method for EPS. It is reported that the valuable metals such as Ni, Cr, Zn, Cu and Sn et al., can extract and recover from the EPS (Li et al., 2007), and the magnetic materials can be prepared from it

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(Chen et al., 2010). But these processes including chemical precipitation, membrane separation, ion exchange, reverse osmosis and solvent extraction, are needed (Matlock et al., 2002; Ko et al., 2010). It is inevitable that the secondary pollution may take place and the high chemical or energy requirements, or high cost has to provide for. In addition, the residue is produced in these processes, and it has to be disposed furtherly. Chen et al. (2009) proves that EPS can be used to stabilize the polymorphs of dicalcium silicate in the belite-rich cement clinkers. But these volatile toxic heavy metals such as Sb, Cd, Pb, Hg and Zn will be emited in the sintering process of clinker at the high temperature above 1400 °C, and will pollute the surrounding environment. The lower cost, more reliable and effective disposal approach for EPS is still the purpose that researcher strives to realize.

The decorative mortar is a type of mortars. It is widely used to replace the paint and ceramic tile to ornament the external wall of building. Its decorative effect is more natural than that of the paint and ceramic tile. Besides these, its thickness and easily treating texture which give architect the larger creative scope than that of other decorative materials, are other interesting reason to use it. Furthermore, the use of cement make it has the stronger price competitiveness than that of other decorative materials. With the aim to adjust the mortar color, various pigments such as ferric oxide, manganese oxide, chromic oxide, ochre and ultramarine commonly have to be used in the preparation process (Lee et al., 2005; Marmol et al., 2010). Generally, their addition contents are about 3% (weight, %) of mass weight of mortar. Their prices are very expensive, and about dozens RMB/kg. The high prices increase the raw material cost of decorative mortar. Consequently, the lower cost pigment is important to further strengthen the decorative mortar competitiveness. Moreover, the issue of resource scarcity is becoming vital as the consumption of material resources is increasing rapidly in both the developed and developing countries (Amir et al., 2013), and natural resources reservation have become global issues (Sabine, 2013). The building material industry, which is known as one of the important consumptive industry for raw material, has integrated these issues to its development policy. The building material industry accordingly is one of the best targets of solid waste reconversion by virtue of the large amounts of raw materials it consumes and the large volume of final products in construction. Such as municipal sewage (Kapshe et al., 2013), incineration bottom ash (Li et al., 2012), recycled beverage and cathode ray tube (Ling and Poon, 2012), old tire (Bravo and Brito, 2012), crushed glass (Disfani et al., 2012) and other solid wastes are recycled and widely used in the production of various building materials.

The EPS presents bright-colored colors because there are many metallic elements, whose ions commonly are provided with various colors. The EPS colors are related to valence states of the metallic elements in it. The composite electroplating sludge (CEPS) is a variety of EPS, and provides with green color mainly because there are a large number ions such as Cu^{2+}, Cr^{3+} and Ni^{2+}, which commonly appear green color. In theory, it can be used as alternative for green pigments in the decorative mortar production. Application of CEPS into the preparation of decorative mortar can not only lead to reduction of management costs, open up new reuse opportunity for EPS and minimize the environment impacts of electroplating industry, but also cut down the decorative mortar production cost, and raise the decorative mortar competiveness. However, there aren't any literature which report the application of dry CEPS into preparation of cement-based decorative mortar as green pigment. Therefore, the possibility of production decorative mortar with CEPS as green pigment is evaluated in this paper. The main physical or mechanical performances including water absorption, compressive strength, flexural strength and tensile bond strength are discussed besides of color, hydration characteristic and heavy metal leachability.

2. Experimental

2.1. Materials

CEPS was obtained from a Shanghai electroplating plant. White Portland cement P.W 52.5R, quartz sand, redispersible emulsion powder VINAPAS 5010N, hydroxypropyl-methyl cellulose ethers 30,000 Pa.s and silicone hydrophobic agent SEAL 80 all were used, and all are commercial products. The main chemical composition of quartz sand is SiO_2, and its mass content is above 99.5%. Quartz sand size is 70–100 ASTM mesh. CEPS was dried to constant weight at 105 °C, and ground to ASTM 200 mesh size with a centrifugal ball mill. Chemical compositions of CEPS and white Portland cement are shown in Table 1.

2.2. Mix design

For all the specimens the mass ratios of water/cement, cement/sand and silicone hydrophobic agent/cement are kept constants at 0.6, 0.43 and 0.03. The mass percent of redispersible emulsion powder is 3. The addition mass content of hydroxypropyl-methyl cellulose ethers is 2%. The differentiation is that the different contents of CEPS are added. CEPS1, CEPS2, CEPS3 and CEPS4 represent respectively the specimens in which 1%, 2%, 3% and 5% CEPS are blended as green pigment.

2.3. Testing methods

2.3.1. Color evaluation

In this procedure, the silicone rubber mold with 6 holes which have the dimensions of 70 mm × 150 mm × 5 mm, was used. The mortars were filled in these holes, and demoulded after cured for 1 d. Then the mortars were continuously cured at 20 ± 2 °C and relative humidity exceeding 90% up to 28 d. The colors for the mortars were evaluated with the color measurement instrument.

2.3.2. Water absorption

The water absorption was measured according to Chinese Building Material Industry Standard JC/T 1024-2007. The specimens were prepared in the molds of 40 mm × 40 mm × 160 mm. The molded specimens were kept at 20 ± 2 °C and relative humidity exceeding 90% for 5 d, and then removed from the molds. The four around surfaces were sealed with epoxy resin after these demoulded specimens continuously cured for 16 d. The sealed specimens were put in the same condition, and cured for 7 d. Then their water absorptions for the 30 min and 240 min were tested.

2.3.3. Compressive and flexural strengths

Firstly, the specimens were casted in accordance with the Chinese National Standard GB/T 17671-1999. Then these 40 mm × 40 mm × 160 mm molded specimens were cured at 20 ± 2 °C and relative humidity exceeding 90% for 5 d. Finally, the compressive and flexural strengths were determined after the demoulded specimens continuously cured at the same condition for 23 d.

2.3.4. Tensile bond strength

The steel plate which has the thickness of 5 mm and 10 holes with the dimensions of 50 mm × 50 mm, was used in this procedure. Before casting, this plate was placed on the clean concrete board which has the same dimension as the steel plate. Then the mortar was put into these 10 holes, and spreaded and smooth with

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