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Durability and environment evaluation of an eco-friendly cement-based material incorporating recycled chromium containing slag

Shukai Cheng [a], Zhonghe Shui [a], Rui Yu [a, *], Xiao Zhang [b], Shouyong Zhu [a]

[a] State Key Laboratory of Silicate Materials for Architectures, Wuhan University of Technology, Wuhan 430070, China
[b] Highway Maintenance Technology Research and Development Centre of Liaoning Provincial Communication Planning & Design Institute., LTD, Shenyang 111011, China

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ABSTRACT

This study investigates the durability of cement-based materials incorporating recycled chromium containing slag (CCS), including chloride permeability, carbonation resistance, freeze-thaw cycle and microstructure development. Additionally, the environmental impacts on the cement-based material with the addition of CCS are evaluated by toxicity characteristic leaching procedure (TCLP), carbon dioxide (CO_2) emission and energy consumption. The obtained results show that the durability properties of chromium containing slag concrete (CCSC) are improved based on the addition of 20–25 wt% CCS and 5–10 wt% silica fume (SF), and the hexavalent chromium (Cr(VI)) can be well immobilized in the cement-based product. Furthermore, the incorporation of recycled CCS can significantly reduce the energy consumption and CO_2 emission of cement-based materials. Based on this study, it is possible to utilize the recycled CCS to produce a clean and durable eco-friendly construction product.

1. Introduction

The rapid development of metallurgical industry, large quantity of chemical heavy metal wastes are generated and emitted into the environment, which has received increasing attention due to its severe impact on human health (De Rosa et al., 1996; Wcisło et al., 2016; Xuan and Poon, 2017). Each year, approximately 1–2 million tons of chromium containing wastes (CCW) are discharged due to the extensive use of chromium in industrial processes and the accumulative total amount is no lower than 6 million (Shi et al., 2007). Large quantity of these CCW contains highly toxic and hazardous heavy metal (Geelhoed et al., 2002), which are classified as a carcinogen associated with the risk of respiratory tract cancer (Batchelor, 2006; Nie et al., 2016) and need to be disposed safely before meeting the environmental substances (Kanagaraj et al., 2015; Wu et al., 2015). Therefore, there is an urgent requirement to solve the problem of CCW treatment for environmental protection and human health.

The solidification/stabilization (S/S) progress of cementitious materials is considered as the "best demonstrated available technology (BDAT)" for hazardous wastes by the US Environmental Protection Agency (USEPA). Due to low cost and high alkaline pH, alkaline substances, such as $Ca(OH)_2$ and cement-based materials, are widely used for immobilization technologies combining with the treatment of hazardous waste (Akcil et al., 2015; Awal and Mohammadhosseini, 2016). Previous investigations showed that the Portland cement (Kindness et al., 1994), the slag cement (Laforest and Duchesne, 2005), and the calcium aluminate cement (Ivanov et al., 2016) were efficient in the immobilization of hexavalent chromium (Cr(VI)). In addition, some pozzolanic materials such as fly ash (Palomo and Palacios, 2003), metakaolin (Sun et al., 2014) and rice hull ash (da Rosa et al., 2015; Pode, 2016) as well as blast furnace slag (Huang et al., 2016; Zhang et al., 2017) were also useful for the Cr(VI) immobilization. However, most of these cement-based materials are economically expensive or reveal some disadvantages such as incomplete immobilization of Cr(VI), high carbon dioxide (CO_2) emissions and energy requirements (Gonzalez et al., 2015; Van Oosten and Maggio, 2015). Hence, these disadvantages severely restrict the application of S/S techniques on treatment of Cr(VI).

During the past few decades, to reuse the recycled CCW more effectively, it has been reported on developing different construction products (Walawska and Kowalski, 2001; Xu et al., 2006).

* Corresponding author.
E-mail address: r.yu@whut.edu.cn (R. Yu).

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When deal with chromium waste, it was revealed that the added chromium containing slag (CCS) decreased the average pore diameter of concrete, and the Cr(VI) could be well immobilized in the hardened cement-based materials, which was beneficial to reducing the chromium leaching (Chen et al., 2013; Shi and Kan, 2009). Nevertheless, the developed CCW based construction products are relatively vulnerable to external environment, such as physical erosion or chemical corrosion. For instance, a study (Chen et al., 2003) reported that the added heavy metals resulted in a reduction of $Ca(OH)_2$ content and thus increased carbonation corrosion of concrete products. Although, some literature suggested that carbonation might resist the leaching of hazardous composites from Portland cement solidified/stabilized waste (Dias, 2000; Zha et al., 2016). Therefore, the durability and reliability of CCW based construction products still need further investigations. However, by far, there is still a lack of systematic studies on the durability of cement-based materials incorporating Cr(VI).

Currently, as pozzolanic reactivity and heavy metal immobilization in cement-based materials are of much interest to concrete technologists. This study aims to evaluate and improve the durability of concrete incorporating recycled CCS as a cement additive. To availably utilize the CCS in the production of cement-based products, the immobilization processes and degree of Cr(VI) are assessed. Furthermore, the environmental impacts on the developed cement-based products incorporating recycled CCS are estimated, employing CO_2 emissions and energy consumption approaches. Moreover, it is possible to effectively reduce the negative environmental impacts on recycled CCS and generate a clean and eco-friendly cement-based product.

2. Materials and methods

2.1. Materials

Ordinary Portland cement (OPC) is obtained from Huaxin Cement Corp. Ltd of China in this study. The commercially available silica fume (SF) is used as raw material. CCS is supplied by Qinghai Puzheng New Mater Co., Ltd. The chemical compositions and physical properties of OPC, CCS and SF are given in Table 1. According to Table 1, the main chemical compositions of CCS are calcium oxide (49.7 wt%), silicon dioxide (29.92 wt%), aluminium oxide (7.1 wt%), magnesium oxide (7.72 wt%) and chromic oxide (4.03 wt%), respectively. The alkaline coefficient K of CCS is 2.16, which can be considered as cementitious active material in accordance with GB/T203-2008 (Chinese National Standard). The photograph and scanning electronic microscopy (SEM) micrograph characteristics of CCS are shown in Fig. 1. Additionally, it can be observed that the main minerals of CCS include larnite (γ-C_2S), spinel ($MgAl_2O_4$), monticellite ($Ca_7Mg(SO_4)_4$) and periclase (MgO),

Table 1
Chemical composition and physical properties of OPC, CCS and SF.

Properties *Chemical composition (%)*	OPC	CCS	SF
SiO_2	21.5	29.92	95.84
Al_2O_3	5.86	7.10	0.17
CaO	59.81	49.70	0.22
Fe_2O_3	2.85	0.31	0.04
Cr_2O_3	–	4.03	–
MgO	2.23	7.72	0.15
SO_3	2.06	0.06	0.47
LOI	3.70	0.54	2.53
Physical properties			
Specific gravity (kg/m^3)	3150	3190	2430
Blaine fineness (m^2/kg)	342	432	3800

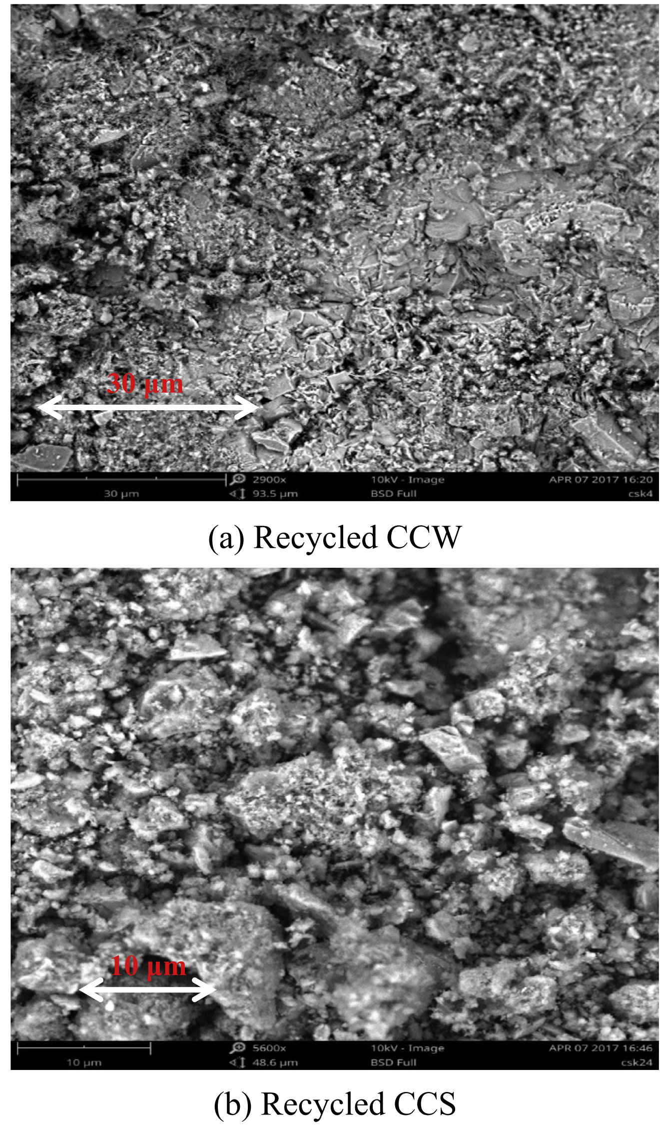

Fig. 1. SEM images of recycled CCW (a) and CCS (b).

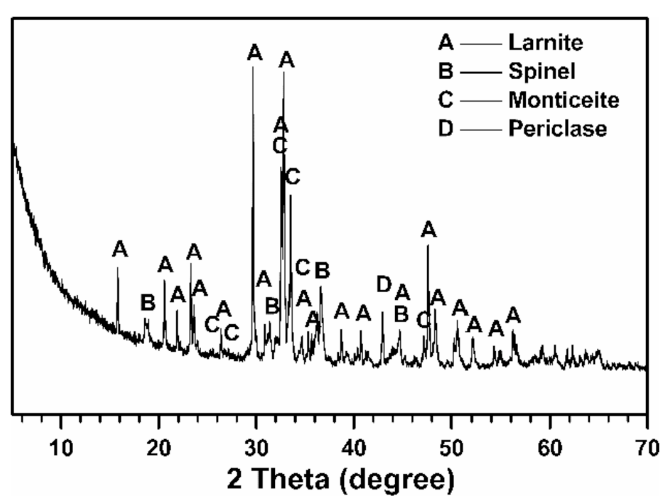

Fig. 2. XRD spectrum of CCS.