Journal of Cleaner Production 51 (2013) 184–190

Contents lists available at SciVerse ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Utilizing recycled cathode ray tube funnel glass sand as river sand replacement in the high-density concrete

Hui Zhao *, Chi Sun Poon, Tung Chai Ling

Department of Civil and Structural Engineering, Hong Kong Polytechnic University, Hong Kong, China

ARTICLE INFO

Article history:
Received 7 December 2011
Received in revised form
18 January 2013
Accepted 20 January 2013
Available online 9 February 2013

Keywords:
Recycled CRT funnel glass
Glass sand
High-density concrete
Properties

ABSTRACT

The rapid advance in the electronics industry has led to the disposal problem related to the cathode ray tube (CRT) glass waste. In this study, the Ordinary Portland cement (OPC) of 15% was replaced by fly ash to mitigate the potential of alkali–silica reaction (ASR) expansion, the crushed nitric acid-treated CRT funnel glass sand (TCF) was used to replace river sand fine aggregate of 0%, 25%, 50%, 75% in the high-density concrete. The fresh, mechanical properties of the high-density concrete containing TCF glass sand were studied, the alkali–silica reaction (ASR) of the mortar and drying shrinkage of the concrete were also evaluated. The test results showed that the use of TCF glass sand improved the fresh properties of the concrete, but reduced the mechanical properties of the concrete. Furthermore, at the drying period of 56 days, all concrete mixtures had an acceptable drying shrinkage value below 0.075%. ASR expansion values of the mortar with TCF glass sand were found to be below the limit of 0.1% at tested age of 14 days. Preliminary results obtained from this study had demonstrated that the CRT funnel glass (an original hazardous material) can be treated, processed and reutilized for the production of the high-density concrete.

1. Introduction

With the rapid increase of liquid crystal display (LCD) used to replace the cathode ray tubes (CRTs) in the computer monitors and the televisions, the amount of discarded CRT has grown rapidly in recent years (Schnoor, 2012; Poon, 2008). It is reported that, in the Western Europe, 300,000 t CRT is expected to become obsolete every year, in the European Union, four-fifths of the total electronic-waste discarded are the CRT waste in 2001, in the United States, one-third of total electronic-waste are the CRT waste in the year 1999, some researchers have predicted that, by 2050 year, the mass of the CRT waste required to be disposed may be 6 times the current mass.

In general, the CRT glass is consisted of three parts glass (neck, panel and funnel), each of them with different chemical compositions and properties. The CRT neck and funnel glass contain high lead oxide content (30 wt.%, 22–25 wt.%) and other dangerous elements, while the CRT panel glass has the relatively low lead oxide content (0–3 wt.%) and other heavy metals (Ba, Sr, etc). A number of studies have demonstrated that the CRT glass can be considered as a hazardous waste, due to its high content of lead oxide and its potential leaching based on tested results of the toxicity characteristics leaching procedure (TCLP). As a result, the CRT glass derived from the televisions and computer monitors has become a major environmental concern in many countries around the world (Socolof et al., 2005), the legislation in Europe and North America has imposed strictly controls on the CRT glass waste. Therefore, the sustainable recycling ways other than landfilling offer a better selection for dealing with CRT waste.

There are two possible ways for discarded CRT glass recycling, the first way is a closed-loop recycling way (recycling CRT glass waste for new CRT glass manufacturing), but, this method seems to be impractical because of the much lower demand for new CRT glass manufacturing after the introduction of liquid crystal display technologies. The second way of recycling CRT glass is to reuse CRT glass waste into another production cycle, i.e. fluxing agent for bricks, glass tiles, from glass (Andreola et al., 2008) and other ceramic product (Andreola et al., 2007; Bernardo et al., 2009), this way is considered not profitable, due to the high cost involved in the separating, sorting, processing of the CRT glass to meet standards required by manufacturers (Ravi, 2012).

Nowadays, a new way to dispose of discarded CRT funnel glass has been developed in Hong Kong, it involves a process of removing, crushing, acid washing and water rinsing. First, the CRT funnel glass is separated from the computer monitors and the televisions by a hot wire separation method. Then, the CRT funnel glass is crushed into a smaller particle size (<5 mm) in a safe manner. After

* Corresponding author. Tel.: +86 18913806637.
E-mail address: njzhaohui@163.com (H. Zhao).

0959-6526/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jclepro.2013.01.025

Table 1
The chemical compositions and physical properties of cement and fly ash.

Chemical composition (%)	Cement (OPC)	Fly ash (FA)
CaO	63.15	<3
SiO_2	19.61	56.79
Al_2O_3	7.33	28.21
Fe_2O_3	3.32	5.31
MgO	2.54	5.21
Na_2O	0.13	0.45
K_2O	0.39	1.34
SO_3	2.13	0.68
Loss on ignition	2.97	3.90
Physical properties		
Specific gravity (g/cm^3)	3.61	2.31
Blaine fineness (cm^2/g)	3519	3960

Table 2
The particle size distributions of fine aggregates and coarse aggregates.

Sieve size (mm)	Cumulative pass amount (%)			
	Fine aggregates		Coarse aggregates	
	R	TCF	5–10 mm	10–20 mm
20	–	–	–	95
15	–	–	100	–
10	–	–	94	18
5	100	100	21	4
4.75	99.05	100	26	–
2.36	94.82	99.14	4	–
1.18	85.99	58.03	–	–
0.6	66.02	19.57	–	–
0.3	32.06	4.85	–	–
0.15	2.1	0.75	–	–
Fineness modulus	2.15	3.22	–	–

that, the lead oxide presented on the surface of the crushed funnel glass is removed by immersing the crushed glass sand in a bath of 5% nitric acid (HNO_3) solution for 3 h. Finally, the acid-treated crushed CRT funnel glass sand (TCF) is removed from the nitric acid bath and thoroughly rinsed using water to remove the remaining acid. TCF glass sand produced in this way has been tested by the toxicity characteristic leaching procedure (TCLP), it satisfies TCLP limit of 5 mg/L as per the requirement of the US Environmental Protection Department (USEPA).

Nowadays, there are some studies to investigate the feasibility of using TCF glass sand as river sand replacement in the mortar, it was found that the presence of TCF glass sand into mortar enhanced the mechanical properties and alkali–silica reaction (ASR) expansion of the mortar, however, ASR expansion value of the mortar with TCF glass sand was below the permitted limit of 0.1%, the further reduction of ASR expansion could be realized by increasing the percentage of fly ash (FA) in the mortar mixture (Zhao and Sun, 2011; Ling and Poon, 2012a). It is generally agreed that utilizing recycled TCF glass sand in the mortar is a promising and effective method for waste CRT glass recycling (Ling and Poon, 2011; Ling et al., 2011). Up to now, some research results about TCF glass sand as fine aggregate in the mortar have been established, however, the study of TCF glass sand as fine aggregate using in the high-density concrete is less documented, the information about the effect of TCF glass sand on the properties of the high-density concrete are still relatively limited (Ling and Poon, 2012b). Therefore, there is an urgent need to investigate the properties of the high-density concrete with TCF glass sand.

In this study, in all the high-density concrete mixtures, the binder materials content was kept at 417 kg/m^3, fly ash (FA) as alkali–silica reaction (ASR) suppressor agent was used to replace Ordinary Portland cement (OPC) of 15%, the water to-binder (W/B) ratio by mass is 0.48, the volume ratio of fine aggregates to total aggregates is 0.42. A series of the high-density concrete samples containing TCF glass sand of 0%, 25%, 50%, 75% (by volume) were prepared. The properties of the high-density concrete, i.e. consistency property, initial slump, wet density, the compressive strength, the tensile splitting strength, the ultrasonic pulse velocity (UPV) and the static modulus of elasticity, were measured. The relationships among these mechanical properties were assessed. The drying shrinkage of the high-density concrete and alkali–silica reaction (ASR) expansion of the mortar were also tested.

2. Methodology

2.1. Materials

2.1.1. Cement (C)

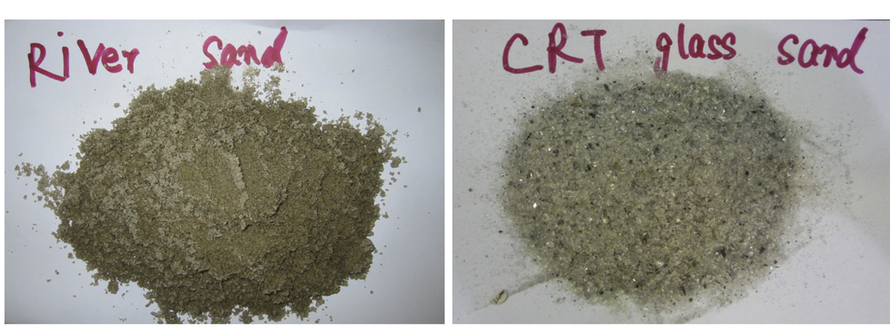
Ordinary Portland cement (OPC) was used in this study. The chemical compositions determined according to BS EN 197 (2000) and physical properties of cement are shown in Table 1.

2.1.2. Fly ash (FA)

In this study, Fly ash (FA) was used as a suppressor agent to prevent alkali–silica reaction (ASR). FA is a by-product during the generation of electricity from a local coal-fired power plant. The chemical compositions and physical properties of fly ash (FA) are given in Table 1.

2.1.3. Aggregates

The natural river sand (R) and TCF glass sand (See Fig.1) were used as fine aggregates, the particle sizes of all the fine aggregates investigated are less than 5 mm. Natural river sand (R) with fineness modulus (FM) of 2.15 was obtained from Hong Kong, TCF glass sand with relatively higher FM (3.22) than river sand (R) was provided by the Environmental Protection



(a) (b)

Fig. 1. Photographs of fine aggregates: (a) Natural river sand (R) (b) The crushed nitric cid-treated CRT funnel (TCF) glass sand.