Construction and Building Materials 47 (2013) 701–710

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

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

Use of recycled alumina as fine aggregate replacement in self-compacting concrete

Gritsada Sua-iam [a], Natt Makul [b,*]

[a] Department of Building Technology, The Project for Consortium on Doctoral Program of Phranakhon Rajabhat University, 9 Changwattana Road, Bangkhen, Bangkok 10220, Thailand
[b] Faculty of Industrial Technology, Phranakhon Rajabhat University, 9 Changwattana Road, Bangkhen, Bangkok 10220, Thailand

HIGHLIGHTS

- Alumina waste (AW) was recycled and reused in self-compacting concrete.
- Fine aggregate was replaced with up to 100% AW by weight.
- Workability of the SCC was satisfactory when AW was added at not more than 75 wt%.
- Addition of 75% AW improved the compressive strength.

ARTICLE INFO

Article history:
Received 4 January 2013
Received in revised form 23 March 2013
Accepted 4 May 2013
Available online 10 June 2013

Keywords:
Recycled alumina waste
Fine aggregate
Self-compacting concrete
Rheology
Mechanical properties

ABSTRACT

Alumina is a common by-product of industrial grit blasting operations. While alumina itself is relatively harmless, the grit blasting waste is regarded as hazardous when contaminated with heavy metals. The concrete industry has initiated the use of solid waste additives in order to address environmental problems. We studied the feasibility of using alumina waste (AW) as a partial replacement for the fine aggregate in self-compacting concrete (SCC). The mixtures were designed to produce a controlled slump flow diameter. The fine aggregate was replaced with up to 100% AW by weight. The rheological and mechanical properties of the SCC mixtures were evaluated based on slump flow, J-ring flow, blocking assessment, V-funnel, air content, compressive strength, and ultrasonic pulse velocity measurements. The filling and passing ability of the fresh concrete decreased in proportion to the alumina content. Mixtures containing up to 75% AW possessed average compressive strengths of 20.9 MPa at 3 days and 45.9 MPa at 28 days.

1. Introduction

Abrasive blasting is a surface cleaning and preparation technique used in many industries. The process involves the forceful direction of an abrasive medium against the surface of a workpiece. The abrasive may be applied either dry or suspended in a liquid. Abrasive blasting originated in 1904 and is currently used for surface cleaning and finishing, stress relief, etching, deburring, and flash removal [1].

Sandblasting waste is the residual material generated during the blasting process and contains the original abrasive material as well as any material that was removed from the target surface. Abrasive blasting is often used to remove paints and primers, and these materials frequently contain chemicals that pose a risk to human health or to the environment. Recycling of the used media into other products may be an economically sound option for large producers of waste [2]. Recently, a number of researchers have studied the possibility of recycling abrasive blasting grit as an aggregate replacement in construction materials. Madany et al. [3] studied the use of copper-containing blasting grit waste as a replacement for marine sand in the manufacture of 15-cm concrete blocks and obtained an average compressive strength of 12 N/mm^2, within the specifications for precast blocks. Leaching test results indicated that the encapsulated waste could be categorized as non-hazardous [4]. Heath et al. [5] examined the hazard potential of abrasive waste from a shipyard, given that many marine coatings include lead-based primers or copper and butyltin-containing antifouling topcoats. The most feasible application for the spent grit was as a partial fine aggregate replacement in asphaltic concrete. A test program was established that included characterization, bench-scale testing, long-term pilot scale testing, and a full-scale demonstration. Full-scale production samples were used to demonstrate that both the chemical leaching resistance and

* Corresponding author. Tel./fax: +66 2 544 8000.
E-mail address: shinomomo7@hotmail.com (N. Makul).

0950-0618/$ - see front matter
http://dx.doi.org/10.1016/j.conbuildmat.2013.05.065

physical performance characteristics were acceptable. By using recycled grit waste in stabilized asphalt mixtures, the shipyard achieved an economic advantage by reducing the costs required for collection, transport, and disposal [6].

The abrasive used in a particular application is usually specific to the blasting method. Because of its cost, longevity, and hardness the most widely used abrasive in sand blast finishing and surface preparation is aluminum oxide. This material has a density of 1.8 kg/L and a hardness of 8 on the original Mohs scale, and is second only to silicon carbide in sharpness [1]. Alumina is normally available in sizes ranging from 24- to 325-mesh [7]. The cost of alumina dictates that it be utilized in enclosed blasting systems to filter and recover the abrasive, since because of its angularity and durability it may be recycled many times. However, the material must eventually be discarded as waste. With respect to its use in construction materials, alumina waste (AW) is characterized as a supplementary cementitious material. Elinwa and Mbadike [8] studied the use of alumina waste for concrete production using mixtures proportioned to produce a cement content of 290 kg/m^3 and a water–cement ratio of 0.40. They determined that the optimum cement replacement level in terms of compressive and flexural strength was 10%. Arimanwa et al. [9] applied Scheffe's simplex theory to develop a model for predicting the compressive strength for AW-containing concrete. The compressive strengths predicted by this model agreed with the corresponding experimentally obtained values, predicting an optimum compressive strength for AW-containing concrete of 28.83 N/mm^2 for mixtures with a water–cement ratio of 0.58 and an alumina content of 38%. The density of the resulting concrete was not significantly affected by the addition of alumina waste, and both the initial and final setting times were decreased. The AW absorbed water from the mix and therefore reduced workability, and mixtures containing large amounts of alumina required higher water–cement ratio than straight cement/sand mixes [10].

Self-compacting concrete (SCC) was introduced in 1988 in Japan to address a lack of skilled workers, and the material has since gained wide acceptance in the construction industry. SCC is highly flowable under its own weight and exhibits good segregation resistance, enabling it to fill voids and surround reinforcements without the need for vibratory compaction during the placing process [11]. SCCs typically have a higher fine particle content and improved flow properties compared to conventional concrete. The self-compatibility of the concrete mixture may be affected by the physical characteristics of the constituents and the mixture proportions, which are intended to provide high flowability while maintaining a low water–cement ratio [12]. The aggregates have a significant influence on the rheological and mechanical properties of the concrete. Their specific gravity, particle size distribution, shape, and surface texture influence the properties of concrete in the fresh state [13]. Several papers have described the successful incorporation of waste materials as partial replacements for fine aggregate in SCC. Ali and Al-Tersawy [14] studied the use of recycled glass and reported that the slump flow increased with increasing glass content, but the mechanical properties of the mixture were inferior. Sua-iam and Makul [15] studied the feasibility of using limestone powder (LS) as a modifying agent in self-compacting concrete in which a portion of the fine aggregate was replaced with untreated rice husk ash (RHA). The fresh properties of the RHA-containing mixtures were improved in mixtures containing less than 60 vol% RHA. Addition of limestone powder improved concrete mixtures containing untreated RHA.

In this work we report the use of alumina waste as a fine aggregate replacement material in self-compacting concrete and describe the effects of alumina incorporation on the mechanical properties of the concrete.

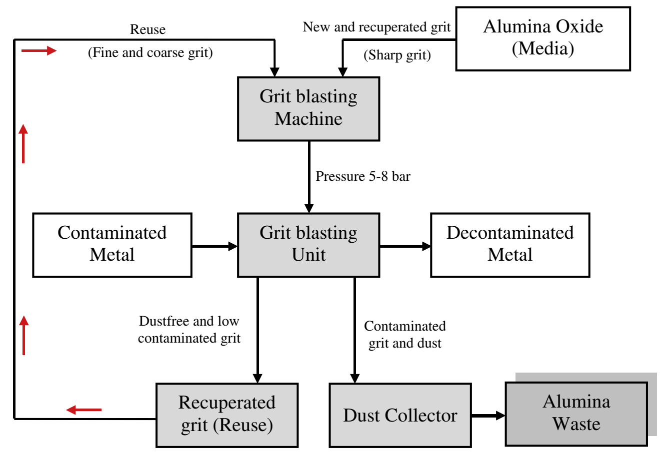

Fig. 1. Schematic diagram of grit blasting process.

2. Experimental program

2.1. Materials

All materials used in this study were obtained locally. The mixtures were prepared using Type 1 Portland cement (OPC) complying with ASTM C150 [16]. Alumina waste (AW) was obtained in the form of used abrasive blasting media from a turbine maintenance facility in Rayong Province, Thailand. The AW was incorporated into the concrete mixtures without prior treatment. The material flow in the grit blasting process is illustrated in Fig. 1.

The chemical compositions and physical properties of the cement and recycled alumina waste are listed in Table 1. Abrasive blasting can generate large quantities of dust containing high levels of toxic air contaminants including chromium, cobalt, nickel, and titanium. A summary of the potential health hazards associated with abrasive blasting air contaminants and their corresponding OSHA Permissible Exposure Limits (PELs) Department of Labor. Abrasive Blasting Hazards in Shipyard Employment. Occupational Safety and Administration (OSHA) Guidance Document [17] are presented in Table 2.

The physical structure of AW and natural sand were examined using a scanning electron microscope (SEM) operating at approximately 1000× magnification (Fig. 2). OPC, AW, and natural sand are crystalline materials (Fig. 3), with the major phases being calcium silicate in OPC, corundum in AW, and quartz in natural sand.

A polycarboxylate-based high range water reducing admixture [HRWR] conforming to ASTM C494 [18] standard type F was also added to the mixtures. The solids content and specific gravity of the HRWR were 42% and 1.05. The HRWR was added in sufficient amounts to obtain a slump flow of 700 ± 25 mm.

Table 1
Chemical composition and physical properties of SCC constituents.

	Type 1 Portland Cement (OPC)	Alumina Waste (AW)
Chemical composition (% by mass)		
Silicon dioxide (SiO_2)	16.39	4.61
Alumina oxide (Al_2O_3)	3.85	84.63[b]
Ferric oxide (Fe_2O_3)	3.48	0.88
Magnesium oxide (MgO)	0.64	0.01
Calcium oxide (CaO)	68.48	0.82
Sodium oxide (Na_2O)	0.06	0.03
Potassium oxide (K_2O)	0.52	0.29
Sodium oxide (SO_3)	4.00	N/D[a]
Titanium dioxide (TiO_2)	N/D[a]	5.34[b]
Dichromium trioxide (Cr_2O_3)	N/D[a]	1.05[b]
Tricobalt tetroxide (CO_3O_4)	N/D[a]	0.86[b]
Nickel oxide (NiO)	N/D[a]	0.91[b]
Physical properties		
Loss on Ignition (% by mass)	1.70	0.01
Particle size distribution (D [4,3] μm)	23.32	47.64
Bulk density (kg/m^3)	1550	1930
Specific gravity	3.20	3.39
Specific surface area (m^2/kg)	610	321

[a] N/D indicates "Not Detected".
[b] Potential air contaminants.