Minerals Engineering 24 (2011) 923–929

Contents lists available at ScienceDirect

Minerals Engineering

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

Effect of fly ash characteristics on the behaviour of pastes prepared under varied brine conditions

Jabulani S. Mahlaba [a,b,*], Elsabé P. Kearsley [a], Richard A. Kruger [c]

[a] University of Pretoria, Civil Engineering, Pretoria 0002, South Africa
[b] SASOL Technology R&D, Environmental Sciences and Engineering, Secunda, South Africa
[c] Richonne Consulting, P.O.Box 742, Somerset Mall, Cape Town, 7137, South Africa

ARTICLE INFO

Article history:
Received 25 January 2011
Accepted 10 April 2011
Available online 11 May 2011

Keywords:
Fly ash
Brine
Paste backfill
Strength development

ABSTRACT

To meet the escalating demand of energy more coal ash and brines are inevitably produced as by-products. Large volumes of these wastes and increasing environmental awareness necessitate the development of more sustainable methods to mitigate the environmental footprint. Paste backfill is one of the potential solutions to keep the energy industry sustainable. The behaviour of pastes was investigated by strategically varying brine composition mixed with the two types of fly ash. The results showed that fly ash plays a more prominent role in the behaviour of pastes than brines. It is therefore imperative to consider both fly ash and brine characteristics i.e. constituents of paste for the development of an environmentally sound paste backfill practice. Technically there are numerous benefits in pursuing the proposed solution.

1. Introduction

The ever-increasing energy demands necessitate combustion of more coal, which is the reliable source of energy worldwide. It is a fact that combustion of low-grade coal generates vast quantities of fly ash of which the global average utilisation is approximately 16% (Ahmaruzzaman, 2010). This leaves the remaining 420 million tons of fly ash requiring measures for disposal annually.

The scarcity of potable water as well as high water consumption during mineral and coal processing leads to the inevitable saline brine production. The management of industrial brines resulting from water recovery processes presents an environmental concern especially inland (Nassar et al., 2008; Souilah et al., 2004; Vedavyasan, 2001), where the option of oceanic disposal is often uneconomical (Ahmed et al., 2003; Nassar et al., 2008; Korngold et al., 2009). The variability of brines as well as failure to meet legal environmental requirements restricts their potential utilisation in applications such as crystallisation of marketable salts, and mixing water in concrete. Literature focuses on the detrimental impact of chlorides in reinforced concrete (Balonis et al., 2010; Neithalath and Jain, 2010; Arya et al., 1990; Barberon et al., 2005) and sulphates to explain concrete deterioration (Medvešček et al., 2006; Collepardi, 2003; Borsoi et al., 2009). These anions give rise to durability problems if they come from the external environment such as the interaction of seawater with concrete.

The study to utilise seawater as mixing water in concrete produced stronger concrete than a control prepared with potable water (Akinkurolere et al., 2007; Taylor and Kuwairi, 1978). Mahlaba and Pretorius (2006) and Mahlaba (2007) indicated that, compared to water, brines have an advantageous effect on the workability of fly ash pastes. The major components in seawater are chloride, sodium, calcium and sulphate (Alahmad, 2010) which most saline brines have been reported to emulate (Ahmed et al., 2003; Ravizky and Nadav, 2007; Mooketsi et al., 2007; Koch, 2002). Furthermore, the use of Cl-bearing compounds to accelerate strength development and improve mechanical properties is common practice in concrete production (Akinkurolere et al., 2007; Taylor and Kuwairi, 1978; Shi, 1996). Na_2SO_4 is used to accelerate pozzolanic reactions whereas gypsum ($CaSO_4{\cdot}2H_2O$) addition controls the setting of concrete (Shi, 1996; Odler, 2004).

Therefore management of both fly ash and brines pose a major environmental risk to surface water and land availability if not properly dealt with. However, the pozzolanic properties of fly ash make it suitable for utilisation in agriculture, waste treatment and cement extension (Shehata, 2001; Muriithi et al., 2011; Kruger and Surridge, 2009; Fester et al., 2008; Vadapalli et al., 2008).

Existing literature focuses on mine backfill with thickened tailings (Jewell and Fourie, 2006; Potvin et al., 2005; Benzaazoua et al., 1999) and rarely on water-based fly ash pastes (Steward and Slatter, 2009; Stropnik and Južnič, 1988; Naik et al., 2009). It was therefore scientifically justifiable to investigate the behaviour of

* Corresponding author at: University of Pretoria, Civil Engineering, Pretoria 0002, South Africa. Tel.: +27 (0)17 619 2500.
E-mail address: sam.mahlaba@sasol.com (J.S. Mahlaba).

0892-6875/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.mineng.2011.04.009

pastes prepared with brines and fly ash; initial results indicated that contaminants are stabilised in paste (Ilgner, 2006; Mahlaba and Pretorius, 2006; Muntingh et al., 2009; Mahlaba et al., 2008). The current authors investigated the influence of industrial brines on the characteristics of fly ash pastes where it was demonstrated that brine chemistry dominates paste behaviour with a given fly ash type (Mahlaba et al., 2011). These findings suggest that co-disposal of these wastes as a paste backfill material will provide an innovative solution which is environmentally less harmful than their individual disposal.

Paste properties (especially its rheology) are influenced by numerous factors of the materials used (Jewell and Fourie, 2006; Verburg, 2001). The present study sheds light on the influence of fly ash characteristics on the brine-based paste behaviour due to site specificity reported in literature (Jewell and Fourie, 2006; Verburg, 2001). Improved understanding of paste behaviour as a function of both fly ash and brine characteristics will potentially lead to the development of a sound backfill solution as well as geotechnical utilisation opportunities. This manuscript makes a significant contribution towards ensuring the sustainability of the coal processing industry.

2. Materials

2.1. Brines

Brines A and B originate from ion-exchange demineralisation (including regeneration chemicals) and thermal evaporation of water at a South African petrochemical plant, respectively. These industrial brines represent the worst case scenarios of brines from most desalination facilities in terms of chemical composition and salinity, and to a certain degree simulate seawater. The chemical composition of these brines and seawater is shown in Table 1.

2.2. Fly ash

Different fly ashes were collected from two South African power stations combusting different coal types to generate electricity using coal-fired boilers. The elemental and mineralogical composition of these fly ashes, namely, fly ashes A and B is provided in Table 2.

2.3. Examination of physical properties

It is well documented in literature that fly ash characteristics principally depend on coal type and combustion method. Finer ash particles are richer in the glassy phase and are more reactive while coarser fractions are richer in carbon (Ward and French, 2006; Nochaiya et al., 2009; Chancey et al., 2010). Spherical fly ash particles reduce friction between particles and improve workability at lower water demands in a paste (Campbell, 1999; Chindaprasirt et al., 2005). Moreover reduced water demand results in a more cohesive paste with minimal bleed formation and low hydraulic conductivity; the cornerstones of good paste (Pagé and Spiratos, 2000; Chindaprasirt et al., 2005; Joshi et al., 1994).

It was considered necessary to discuss physical characteristics of fly ash in addition to chemical properties to enable better interpretation of paste behaviour. The fundamental physical characteristics of fly ash examined are colour, particle size distribution, and particle morphology.

2.3.1. Colour

There is a significant colour difference between the two fly ashes where fly ash A is greyish like ordinary cement and fly ash B is brownish[1] as depicted in Fig. 1. Such a difference can be assigned to an appreciably higher concentration of iron in fly ash B (Table 2) i.e. chemical composition.

2.3.2. Particle morphology

It is illustrated in Fig. 2 that the majority of particles in fly ash A has a spherical morphology while that of fly ash B is rather irregular as depicted in Fig. 3. Therefore pastes prepared with fly ash A

Table 1
Chemical composition of brines A, B and seawater.

Component	Unit	Brine A	Brine B	Seawater
pH	–	7.4	8.8	8.2–10.0
EC	µS/cm	70,400	124,000	–
Ca^{2+}	mg/l	341	2100	500
Mg^{2+}	mg/l	238	1550	1550
Na^{+}	mg/l	19,227	21,000	12,000
Cl^{-}	mg/l	14,668	34,300	22,000
$SO_4^{=}$	mg/l	5931	15,200	3000
TDS	mg/l	44,400	108,000	39,806–45,000

#TDS = total dissolved solids.

Table 2
Elemental and mineralogical composition of fly ashes A and B (%).

Component	Fly ash A	Fly ash B
Elemental composition (%)		
SiO_2	49.7	59.5
Al_2O_3	26.2	28.5
Fe_2O_3	2.7	5.9
CaO	10.5	2.3
MgO	2.1	0.4
SO_3	0.5	0.4
Na_2O	0.7	–
K_2O	0.9	1.0
TiO_2	1.5	1.3
Loss on ignition (LOI)	4.1	–
Other	0.9	0.7
Total	99.8	100.0
Mineralogical phase (%)		
Mullite ($Al_6Si_2O_{13}$)	20.53	28.98
Quartz (α-SiO_2)	10.24	11.86
Hematite (Fe_2O_3)	0.68	1.43
Lime (CaO)	2.22	0.37
Glassy phase	66.33	57.36
Total	100.0	100.0

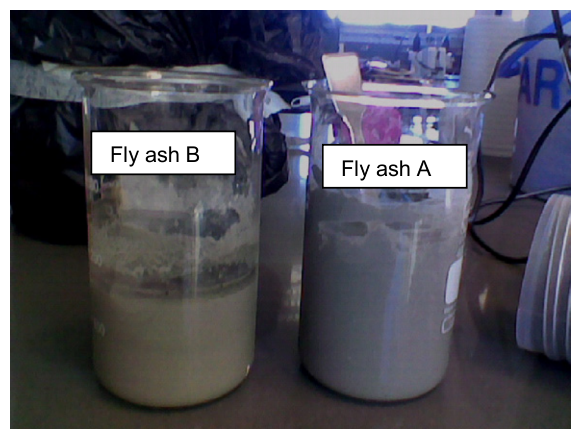

Fig. 1. Picture showing colour difference between fly ash A and B.

[1] For interpretation of colour in Fig. 1, the reader is referred to the web version of this article.