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ScienceDirect
Fuel 87 (2008) 359–364
FUEL
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Durability of biomass fly ash concrete: Freezing and thawing and rapid chloride permeability tests

Shuangzhen Wang [a], Emilio Llamazos [a], Larry Baxter [a,*], Fernando Fonseca [b]

[a] *Department of Chemical Engineering, 350 CB, Brigham Young University, Provo, UT 84602, United States*
[b] *Department of Civil Engineering, Brigham Young University, UT, United States*

Received 1 September 2006; received in revised form 7 April 2007; accepted 3 May 2007
Available online 11 June 2007

Abstract

Strict interpretation of ASTM C 618 excludes non-coal fly ashes, such as biomass fly ashes from addition in concrete. Biomass fly ash in this investigation includes (1) cofired fly ash from burning biomass with coal; (2) wood fly ash and (3) blended fly ash (wood fly ash mixing with coal fly ash). A set of experiments conducted on concrete from pure cement and cement with fly ash provide basic data to assess the effects of several biomass fly ashes on the performances of freezing and thawing (F–T) and rapid chloride permeability test (RCPT). The F–T tests indicate that all fly ash concrete has statistically equal or less weight loss than the pure cement concrete (control). The RCPT illustrate that all kinds of fly ash concrete have lower chloride permeability than the pure cement control concrete.

Keywords: Biomass fly ash; Permeability; Freezing and thawing

1. Introduction

Biomass combustion is assumed to be CO_2 neutral process if its consumption rate is less than its growth rate, which is environmentally friendly and arouses great interests of the world. However, biomass fly ash is excluded from addition in concrete by ASTM C 618 because of its ‘‘non-coal’’ origin.

Entrainment of small air bubbles in the range of micro or nanometers imbues concrete with resistance to freezing and thawing degradation [1]. The benefit of air entrainment of concrete is shown in Table 1 and thus adequate amount of air content is crucial to the durability of concrete in related to F–T [2].

Coal fly ash addition has little direct effect on the concrete performance by freezing and thawing, but it does affect the air content of concrete mixes through the behaviors of air-entraining agent (AEA) [2–4] and mostly likely brings severe air loss within 2 h of mixing [3]. Unburned carbon residue, the main form of LOI in the fly ash, adsorbs AEA; and the adsorption capacity not only depends on the amount of LOI, but also more on the carbon forms and surface area available in LOI [5–7]. Furthermore, water soluble alkalis from fly ash and cement decrease air-entraining agent amount in concrete [8].

It is generally agreed that Class C fly ash has less carbon than Class F; therefore, Class C fly ash need less AEA demand than Class F in concrete mix. Furthermore, if suitable amount of AEA is added in fly ash concrete to produce desirable air void, fly ash does not affect the F–T behavior too much.

Biomass fly ash generally has more alkali and more LOI than coal fly ash [9,10] and its mineralogical composition with coal fly ash can be also different [11,12]. High alkali content can cause serious alkali silica reaction (ASR) expansion concerns, and high LOI will have the same effect as that from coal fly ash, causing unstable air content leading to poor durability by F–T if not dealt properly. However, the research by the same authors from BYU have studied the effect of cofired (biomass with coal) fly ash on

* Corresponding author. Tel.: +1 801 422 8616; fax: +1 801 422 0151.
E-mail addresses: wangshuangzhen@gmail.com (S. Wang), larry_baxter@byu.edu (L. Baxter).

0016-2361/$ - see front matter
doi:10.1016/j.fuel.2007.05.027

Table 1
The effect of air content on durability factor [1]

Air content (%)	Durability factor (%) by ASTM C 666
<3	<80
>4	>85

ASR expansion, and the results show that although biomass fly ash has much more available alkali than that of Class C fly ash, it is still more effective in reducing ASR expansion [13].

Permeability is an important property of concrete. Low permeability delays ionic and moisture transfer within concrete and prevents chemical erosion or attack in chemically severe environments. Permeability mainly arise from large capillary pores rather than gel pores in the cement paste; therefore, the level of concrete permeability mainly depends on water/cement ratio, curing conditions and period [1,14].

Chloride creates severe corrosion concern for steel available in concrete [1]. In ASTM C1202 and AASHTO T277, the chloride ions penetration is measured by the total charges passed exerted by an external electrical field. This procedure is inappropriate and upon criticism because (1) all the ions (instead of chloride ions only) contribute to the charges measured in this test [15]; and (2) the measured values also depend on the chemistry of pore solution [16,17].

Despite what should be the appropriate method for chloride penetration measurement, the following discussion will focus on the fly ash's effect on RCPT guided by ASTM C 1202. One contribution to RCPT by fly ash addition comes from the modification of concrete pore size distribution. This process mainly depends on the particle size distribution of fly ash (physical filling effect) and the formation of secondary C–S–H gels by pozzolanic reaction, both of which have close relationship with fly ash/cement ratio [14,18–25]. The ions leached out from fly ash modify the pore solution, thus contributing to the rapid chloride permeability [17,26]. Since biomass fly ash has potentially higher alkali content than coal fly ash, the reduction of RCPT by biomass fly ash addition is potentially less efficient than that of coal fly ash.

Although chloride ions penetration can be measured by other alternate methods such as long time chloride pounding test [27], results from other researchers still show the consistency of RCPT by itself (in short time, say one month and long term,say one year) and with other tests. At 20–30% replacement ratio of cement by fly ash, fly ash concrete is significantly less permeable than cement only concrete even from one to three months curing; and this trend goes up to one year or longer depending on the availability of test data [14,28–30]. At 90-day after concrete mixing, results of RCPT are quite consistent with those from chloride ponding tests [31].

Further study of pozzolanic reaction kinetics has found that at one month curing, coal fly ash (Class C and F) and biomass fly ash (either cofired or wood fly ash by itself) have undergone significant pozzolanic reactions at ambient temperatures [32], which can explain why fly ash can reduce concrete chloride permeability at shorter period within two months.

2. Experimental materials and concrete mix design

2.1. Materials

There are seven types of fly ash involved in this investigation, (1) two coal fly ashes, Class C and Class F; (2) two cofired (biomass and coal) fly ashes, SW1 (20% switchgrass burned with 80% Galatia coal, wt%), SW2 (10% switchgrass burned with 90% Galatia coal, wt%); (3) wood fly ash from wood combustion; (4) two blended fly ashes, Wood C and Wood F, which comes from blending wood ash (20 wt%) with either Class C or Class F (80 wt%), respectively.

All other fly ashes except wood have similar particle size with major portion in the range of 3–50 μm, and most wood fly ash falls in the range of 30–130 μm. Galatia coal produces Class F fly ash by itself; therefore, it is reasonably postulated that SW1 and SW2 behave more like Class F fly ash due to the major portion of coal in the cofiring process.

The detailed information of fly ash, such as particle size distribution and chemical composition, and the specification of cement and aggregates, are given in another paper [33].

The AEA used in this project is AMEX 210, which is from Grace Construction Products and popularly used as common concrete mixes.

2.2. Concrete mix design and strength build-up

The concrete mix design has the following parameters: (1) fly ash/cement = 25/75 (wt%); (2) water/(fly ash + cement) = 0.5 (wt%); (3) slump 7.5–12.5 cm (3–5 inches) and (4) air content 4–6% (volume). Detailed information of concrete mix design is given elsewhere [33].

3. Experimental procedures

3.1. Resistance to freezing and thawing

Procedures from ASTM C666 are followed in the F–T test of concrete specimens. Weight loss percentage is reported for all the eight mixes while durability factors were reported only for wood and Class F mix, because the freezing and thawing machine performed properly only during the tests of these two mixes. Typically, three specimens for one concrete mix are applied for the targeted tests.

3.2. Rapid chloride permeability test

On the 55th day of moisture curing, two 5-cm thick specimens were prepared from a 10.2-cm (diame-