

Biomass fly ash in concrete: Mixture proportioning and mechanical properties

Shuangzhen Wang^a, Amber Miller^a, Emilio Llamazos^a,
Fernando Fonseca^b, Larry Baxter^{a,*}

^a Department of Chemical Engineering, Brigham Young University, 350 CB, Provo, UT 84602, USA

^b Department of Civil Engineering, Brigham Young University, Utah, USA

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Abstract

ASTM C 618 prohibits use of biomass fly ashes in concrete. This document compares the properties of biomass fly ashes from cofired (herbaceous with coal), pure wood combustion and blended (pure wood fly ash blended with coal fly ash) to those of coal fly ash in concrete. The results illustrate that with 25% replacement (wt%) of cement by fly ash, the compressive strength (one day to one year) and the flexure strength (at 56th day curing) of cofired and blended biomass fly ash concrete is statistically equal to that of two coal fly ash concrete in this investigation (at 95% confidence interval). This implies that biomass fly ash with co-firing concentration within the concentration interest to commercial coal-biomass co-firing operations at power plants and blended biomass fly ash within a certain blending ratio should be considered in concrete.

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1. Introduction

Strict interpretation of ASTM C618 (and most standards in other countries addressing a similar issue) precludes the use of any material not derived from coal combustion. The fraction of fly ash that qualifies under this strict interpretation for use in concrete is in rapid decline due to issues such as co-firing fuels with coal and injecting a variety of materials for emissions control.

Biomass coal co-firing represents possibly the most cost effective and efficient means of renewable power production other than hydropower. In this scenario, typically less than 10% biomass by energy content combines with coal in a traditional, large-scale coal combustor. In this way, the relatively high percentages of coal can be combined with

the renewable energy characteristics of biomass and the existing capital equipment to produce cost effective and efficient renewable power, the fraction of total power derived from the biomass being renewable.

Typically, fly ash from neat biomass combustion has more alkali (Na and K) and less alumina (Al_2O_3) than coal fly ash [1,2]. As a class, biomass fuels exhibit more variation in both composition and amount of inorganic material than is typical of coal. Therefore, biomass fly ash varies more than coal fly ash, which depends on the varieties of origin from woody to herbaceous and other resources [3,4]; furthermore, even for the same type of biomass, the properties of its fly ash depends also on some growth and production factors including weather, season, storage and geographic origins [4–6].

Many kinds of biomass fly ash have similar pozzolanic properties as coal fly ash, such as those from rice husk, wood, wheat straw and sugar cane straw [7–10], among which have been added in concrete as mineral admixtures, improving the performance of concrete.

* 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).

The realities of popular co-firing less than 10% biomass with coal in industry lead to relatively low amounts of biomass-derived material in the combined fly ash stream. Therefore, these streams can usefully be thought of as coal fly ash with minor but not necessarily insignificant biomass-derived additional material [11], which should be potentially qualified as mineral admixture in concrete because of the dominant co-firing portion of coal.

2. Classification issues

Fly ash with potential use in concrete includes Class C and Class F material under current standards such as ASTM C 618. The classification is based on sum of ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$). However, the fly ash composition could be quite different from that of *fuel ash* and this mainly comes from the existence of SO_3 , which could lead to significant error of predicting which coal produces Class C or Class F fly ash. The significance of this discussion is that fly ash classification should not rely on unduly on fuel ash data, especially if the fly ash falls close to the cut off for a given fuel.

The term *fuel ash* indicates the ash formed from a fuel sample following laboratory procedures, that is, during the determination of ash and ash composition from a fuel sample. The term *fly ash* refers to material collected from a practical combustion device after the fuel is consumed.

SO_3 forms a small fraction of high-rank fuel ashes and that fuel ash provides reasonably accurate estimations of fly ash composition from these fuels so far as SO_3 is concerned, with about 95% of both fuels forming Class F fly ashes.

For low-rank fuels, the SO_3 content in fuel ash is typically 4–5 factors higher than that in fly ash from the same fuel, making the ash qualified as Class C based on fly ash composition but disqualified based on fuel ash composition. While for high-rank coals, since they contain much less sulfur by themselves, this effect is much less compared to that on low-rank coal.

Fig. 1 illustrates results from 79 sample analyses focusing on SO_3 mass fractions. Fuel and fly ash samples come from the same coals in all cases, with sufficient replication to generate 95% confidence intervals for means of each data set. Both the amount of sulfur in the fly ash and the difference in the fuel ash and fly ash sulfur contents is much lower for bituminous and other high-rank fuels.

Fig. 2 summarizes statistical data on more than 7000 coal ash samples plotted as a function of rank. The limits for Class C and Class F classifications appear in the figure at 50% and 70%, respectively. The figure illustrates that, based on fuel ash analyses, about 50% of all lignites and 68% of subbituminous coals form fly ash that meets the Class C standard. However, the data in Fig. 1 suggest that such fuel ash analyses, while convenient, overestimate the actual amount of SO_3 in fly ashes formed from these fuels by factors ranging from 2 to 8 and typically by factors of 4–5. If there were no sulfur in the fly ash, the figure

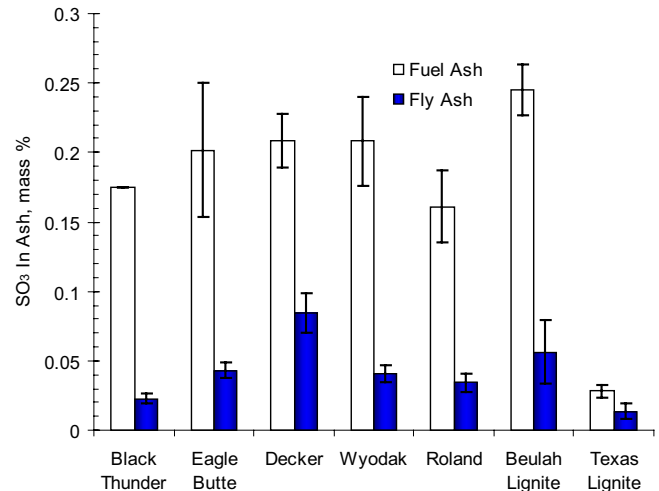


Fig. 1. Comparison of SO_3 in fuel ash (ash analyzed from fuel sample) compared to that in fly ash samples of the same subbituminous coals (first five) and lignite.

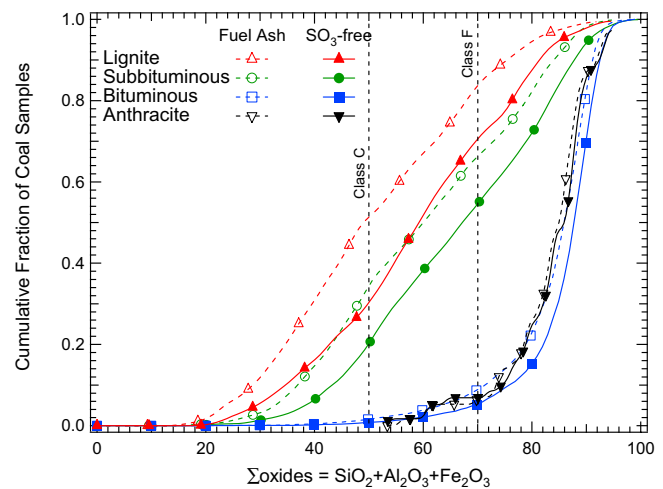


Fig. 2. Cumulative fraction of fuel ash samples with sums of SiO_2 , Al_2O_3 , and Fe_2O_3 below the value indicated on the abscissa plotted as a function of coal rank and on as-analyzed and SO_3 -free bases.

indicates that the fractions of fuel that meet the Class C standard increase from 50% to about 78% for lignites and from 68% to about 80% for subbituminous coals. While the fly ash SO_3 content is probably much less than the fuel ash suggests, it is not zero. If the SO_3 in fly ash approximates that in the fuel ash reduced by the 75–80% that Fig. 1 suggests is typical, the percentages of fuel that meet the Class C standard increase from 50% to about 73% for lignites and from 68% to about 78% for subbituminous coals. These last estimates are not included in the figure.

Fig. 3 includes data similar to Fig. 2 but for biomass samples. The biomass data are based on over 120 samples each for herbaceous and woody fuels, but this represents a much smaller database than the more than 7000 results on which Fig. 2 is based. The SO_3 -free lines for bituminous and subbituminous coals are included for comparison in

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