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Pozzolanic activity of feedlot biomass (cattle manure) ash

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ABSTRACT

The pozzolanic activity of cattle manure ash (CMA) was determined and compared with fly ash (FA) in this study. X-ray diffraction (XRD) and energy-dispersive analysis (EDA) were used to determine the chemical composition of the CMA and FA. Scanning electron microscope (SEM) images indicated that the microstructure of the CMA is mainly in the shape of floccules. Mortar prism and concrete cube specimens were tested to determine the reactivity of CMA; the compressive strength of CMA mortar was found to be greater than that of FA mortar. The same result was obtained for concrete cube compressive strengths at 7, 28 and 56 days. Tests of electric flux to assess chloride anion penetration resistance of the concrete gave the CMA concrete the highest results for the four materials after 28 days, and least after 180 days. These results indicate that the pozzolanic activity index of CMA exceeds that of FA, indicating that CMA is a suitable replacement for cement in the preparation of concrete. Such a result can assist the cattle raising industry to drastically reduce waste disposal problems.

1. Introduction

In China, cattle raising is an attractive industry which provides abundant products and assists the economy. However, cattle manure causes environmental problems and has a serious negative effect on the industry. Statistics, although incomplete, indicate that there are currently 2.16 billion cattle on farms in China; each beast produces approximately 8.2 tons of collectable manure per year, containing 35% moisture and 65% solids (combustibles + ash) [1,2]; this totals some 17.7 billion tons of cattle manure in a year. In many cases, the production of manure from one or more animal species is more than can be safely applied to farmland in accordance with nutrient management plans, and stockpiled waste is an economic and environmental liability. This bio-waste contributes to surface- or groundwater contamination and air pollution by releasing CH_4 (a greenhouse gas), NH_3, H_2S, amides, volatile organic acids, esters, and others compounds [1,2]. With the gradually increasing number of cattle impacting on feed and energy resource requirements in China, the development of alternative uses for feedlot manure may become more attractive in some cattle feeding areas in the future. Biogases produced by mixing cattle manure with additives have been used for fuel and to generate power [3]; for example, biogas obtained for these purposes from mixtures of cattle manure and straw has been reported [4,5].

Unfortunately, anaerobic digestion is a slow process with resulting release of emissions over a long period of time (10–30 days), and the process requires liquefaction using water, which may be scarce in some areas. Transporting digested slurry is difficult, and the solids content of the slurry poses chronic mechanical problems; therefore, a method entailing combustion of cattle manure may be the optimal choice to solve most of these problems [6]. The results of studies by Annamalai, Sweeten and others on the combustion of cattle manure in a fluidized bed combustor have indicated that burnt cattle manure can be translated into other forms of energy [7–12]. For example, in 2004 Constellation Energy invested US $4,600 m to build a power station using cattle manure as a fuel in Imperial Valley, southern California [13].

Combustion is potentially the most attractive method of cattle manure disposal for several reasons: the shorter time taken compared to anaerobic digestion; the fact that combustion can be used to generate energy; it protects the environment from pollution; and it is economical. Nevertheless, a considerable amount of ash residue remains, since CMA represents about 30% of dried cattle manure [2]. This means that, in China, 3.45 billion tons of CMA per year would be generated by combustion if all the collected cattle manure were burned, based on the above figures ($17.7 \times 0.65 \times 0.3 = 3.45$). Such a quantity of CMA would still occupy much farmland and cause pollution problems.

Reports of previous research have generally discussed the combustion of cattle manure solely in terms of electricity generation without reference to the use or disposal of the resulting ash, with three exceptions [13–15] in which the idea of using CMA in cement and concrete mixes was introduced; however, the reasons for CMA

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usefulness in cement and concrete were not explained. In the present study, by contrast, the chemical composition of CMA was determined by X-ray diffraction and energy-dispersive analysis techniques, and its microstructure was determined by scanning electronic microscopy. Mortar prism and concrete cube specimens were tested to determine the reactivity of CMA, and its pozzolanic activity index was compared with that of FA in order to assess its future applicability for concrete and mortar.

2. Materials and methods

2.1. Materials

2.1.1. Cement

Ordinary Portland cement obtained from Qinling Cement Manufacturing Company of Shaanxi Province in China and conforming to *Common Portland Cement* (GB 175-2007/XG1-2009) [16] was used as received. The chemical and physical properties of the cement are shown in Table 1.

2.1.2. Cattle manure ash (CMA)

CMA produced in the combustion of cattle manure in a boiler furnace was used as received. The ash was sieved to obtain material smaller than 4.75 mm. The chemical and physical properties of the CMA are shown in Table 1.

2.1.3. Fly ash (FA)

FA obtained from a power generating station in Shaanxi Province conforming to *Fly Ash in Cement and Concrete* (GB/T 1596-2005) [17] was used as received. The water-demand ratio of the FA was 87.5%.

2.1.4. Aggregates

Locally available natural sand with particles smaller than 4.75 mm, fineness modulus of 2.39, and specific gravity 2.60 g/cm^3, along with China ISO Standard sand produced by Xiamen ISO Standard Sand Co., Ltd., was used as fine aggregate.

Crushed basalt (maximum size 30 mm, specific gravity 2.9 g/cm^3) was used as coarse aggregate.

2.1.5. Chemical admixture

A naphthalene-based high-efficiency water-reducing additive conforming to *concrete admixture* (GB8076-1997) [18], obtained from Longhui Manufacturing Company in Shanxi Province, was used as received. The additive was in solid form; the additive quantity was 1–1.4% of binder. The proportion of water-reducing additive was 24.7% of the water in the control concrete.

2.1.6. Mortar mix proportions

Three kinds of mixture were used in the experiment. The pozzolanic activities of FA and CMA in the different mixes were evaluated for comparison. The ratio of water to binder in this series of mixes was set at 0.5. The binder content in all mixes was 450 g; mix proportions are given in Table 2.

2.1.7. Concrete mix proportions

Four series of concrete mixes, N_1-FA_1 to N_4-FA_4, were prepared by replacing 10%, 15%, 20% and 30% of the cement by CMA and FA, respectively. To compare the pozzolanic activity of the CMA and FA, strength test specimens were prepared for both CMA and FA concretes. The ratio of water to binder in this series of mixes was set at 0.55; mix proportions are given in Table 3.

Two control mixes were also prepared: J_1 series control mixes comprised coarse aggregate, fine aggregate (natural sand), cement and water; and J_2 series control mixes consisted of coarse aggregate, fine aggregate (natural sand), cement, water and water-reducing additive (Table 3).

Table 1
Chemical composition and physical properties of Portland cement, FA and CMA (wt.%).

	Chemical composition										
	SiO_2	CaO	Al_2O_3	K_2O	Fe_2O_3	MgO	P_2O_5	SO_3	Cl	Na_2O	Loss by ignition (%)
Cement	47.6	9.17	27.0	1.93	4.97	1.08	0.32	1.29	–	0.72	0.75
CMA[a]	52.0	15.4	7.79	4.91	3.20	2.94	2.92	1.54	0.35	0.66	2.5
FA[b]	55.2	1.58	4.04	1.29	3.23	1.73	–	4.45	–	0.51	0.99

Physical properties	Specific gravity (g/cm^3)	Specific surface (BET) (cm^2/g)	Color
Cement	1.875	8751	Gray (50%) + black (50%)
CMA[a]	0.81	5618	Gray (40%) + black (60%)
FA[b]	2.2	5572	Gray

[a] Cattle manure ash.
[b] Fly ash.

Table 2
Mortar mixture proportions.

	Cement (g)	CMA[a] (g)	FA[b] (g)	China ISO standard sand (g)	Water (g)	W/B[c]
R_0	450	–	–	1350	225	0.5
R_1	315	135	–	1350	225	0.5
R_2	315	–	135	1350	225	0.5

[a] Cattle manure ash.
[b] Fly ash.
[c] Water:binder ratio = 0.5.

Table 3
Concrete mixture proportion.

	CMA[a], FA[b] (%)	CMA[a], FA[b] (kg)	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (kg)	SP[c](kg)	W/B[d]
J_1	0	0	364	753	1083	200	–	0.55
J_2	0	0	364	753	1083	200	4.4	0.55
N_1,FA_1	10, 10	46, 46	328	720	1083	206	4.4	0.55
N_2,FA_2	15, 15	68, 68	309	715	1083	208	4.4	0.55
N_3,FA_3	20, 20	91, 91	291	709	1083	210	4.4	0.55
N_4,FA_4	30, 30	137, 137	255	699	1083	215	4.4	0.55

[a] Cattle manure ash.
[b] Fly ash.
[c] High-efficiency water-reducing additive.
[d] Water:binder ratio = 0.55.