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Effect of cattle manure ash on strength, workability and water permeability of concrete

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HIGHLIGHTS

- Cattle manure ashs on strength, workability and permeability of concrete is studied.
- Influence of three cattle manure ashs on the mixing way of the concrete is studied.
- Mechanical mixing and vibration is the optimum when CMA is used in concrete.
- Character of the CMA-M (combustion temperature 500 °C) concrete display the best.

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ABSTRACT

Combustion is an attractive method for cattle manure waste disposal since it produces heat and electrical energy and minimizes groundwater and air pollution by consumption of the waste. A major problem arising from the combustion of cattle manure waste is the significant resultant quantity of cattle manure ash (CMA). In this paper, we study the strength, workability and water permeability of concrete when CMA is used as a partial replacement in cement. Three types of CMA were tested, namely CMA, CMA-M and CMA-U, which were generated after combustion at 200 °C, 500 °C and 800 °C. The strength of concrete that contained CMA was determined using cubic samples (100 mm edge) at 7, 28 and 56 days. The workability was measured from the slump when the concrete was mixed manually or mechanically. The water permeability, including percentage, velocity and coefficient of water absorption of concrete, was determined at 7, 28 and 90 days using an improved initial surface absorption test. The workability increased from CMA to CMA-M to CMA-U. The compressive strength increased with increasing particle size from CMA to CMA-M but decreased from CMA-M to CMA-U. The water permeability, including percentage, velocity and coefficient, increased from CMA to CMA-M to CMA-U at 7 and 28 days. At 90 days, the water permeability, including percentage, velocity and coefficient of water absorption of CMA-M concrete, were the lowest in the three CMA concretes. CMA-M was the best material in terms of its overall workability, strength and water permeability. Mechanical concrete mixing and vibration was the optimal preparation procedure. CMA can therefore be blended with cement for concrete production depending on the ultimate use.

1. Introduction

Disposal of manure from beef cattle feedlots has come under heavy scrutiny because of increased concerns over land, water and air pollution. Incineration of manure at an appropriate temperature is a viable option to reduce pollution and produce ash that can be used as a material resource in the construction industry.

Cattle manure is a major source of biomass in China because it exists in large quantities and is high in energy [1–3]. In 2010, ~3.84 billion tons of cattle manure ash (CMA) would have been generated in China if all the country's cattle manure had been combusted. Data have indicated that although the generation of CMA requires large areas of land, the Chinese supply is sufficiently large to be applied in other uses such as plant nutrition. CMA can be

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used to replace some of the cement in concrete [4–7] and to make thermal insulating building blocks [8,9]. Several authors [4–9] have investigated the effect of quantity of cement replaced and age on CMA concrete strength. For example, Thomas and Percival determined the optimum cattle manure combustion temperature to produce CMA and how CMA replacement influences concrete strength at different times. Because of combustion conditions, such as temperature, the chemical and physical properties of the biomass ash, its particle size distribution, its loss on ignition (LOI) and unburned carbon content will differ [10]. These properties of the biomass ash affect the concrete properties [11]. In this study, we investigate the effect of the partial replacement of cement with various types of CMA produced using three combustion temperatures on the compressive strength, workability and water permeability of concrete, with the aim of developing CMA with optimal structural properties for use in concrete.

2. Experimental procedure

2.1. Methods

2.1.1. Chemical composition of the materials

X-ray fluorescence was used to determine the chemical composition of CMA and Ordinary Portland cement (OPC).

2.1.2. Mineralogical composition

X-ray diffractometry (XRD) was used to determine the mineralogical composition of CMA and OPC, using a Broker-AXS D8 Discover diffractometer operating with Co Kα radiation and a scanning angle (2θ) from 20° to 80°.

2.1.3. CMA and OPC morphology

The CMA and OPC particle morphology were studied by scanning electron microscopy using an accelerating voltage of 15 kV, and after gold coating the samples.

2.1.4. CMA and OPC particle size distributions

A Mastersizer 2000 was used to identify the particle size distributions of the CMA and OPC.

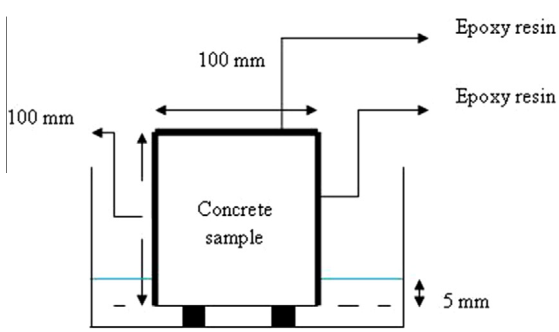

Fig. 1. Water absorption velocity and coefficient of water absorption test.

2.1.5. Concrete workability

The concrete was mixed manually and mechanically for more than 5 min and less than 3 min, respectively. Concrete slumping was tested according to a proprietary standard test for concrete mixtures, termed GB/T 50080-2002 [12].

2.1.6. Concrete cube compressive strength

According to the standard mechanical test for concrete (GB/T 50081-2002) [13], the mixture was placed in a cubic mould with 100 mm edge and vibrated until the grout was visible on the concrete surface after manual and mechanical mixing. The concrete sample was removed from the mould after 24 h and placed in a curing room (at 20 ± 3 °C and a humidity greater than 95%) to cure to 7, 28 or 56 days. The concrete compressive strength was tested at these times.

2.1.7. Percentage water absorption

The percentage of water absorbed by the CMA-blended concrete samples was measured based on ASTM C 642 2006 after 7, 28 and 90 days of moisture curing.

2.1.8. Velocity and coefficient of water absorption

According to Givi et al. [14], the velocity and coefficient of water absorption of the CMA-blended concrete samples was measured after 7, 28 and 90 days of moisture curing, as shown in Fig. 1.

2.2. Materials

2.2.1. Cement

OPC was procured from the Qinling Cement Manufacturing Company in Shaanxi, China. The cement was used as received and conformed to Common Portland Cement (GB175-2007/XG1-2009) regulations [15]. The chemical and physical properties of the cement are shown in Table 1.

2.2.2. Biomass CMA

A local supplier who uses controlled incineration produced a series of CMA samples. The as-received CMA was generated by natural combustion at approximately 200 °C, without temperature control, after which it was cooled naturally. The as-received CMA-M and CMA-U were generated from CMA that had undergone a second combustion round at 500 °C and 800 °C, respectively, for 2 h, and had then been cooled naturally. The as-received ash was sieved at 47.5 mm and samples of these three varieties were used in the experiments.

2.2.3. Aggregates

Locally available natural sand finer than 4.75 mm (fineness modulus of 2.39, specific gravity of 2.60 g/cm^3), and China ISO Standard sand that was produced by the Xiamen ISO Standard Sand Co. Ltd. was used as the fine aggregate. Crushed basalt (maximum size 30 mm and specific gravity of 2.9 g/cm^3) was used as the coarse aggregate.

2.2.4. Chemical admixture

Solid sulfonated naphthalene formaldehyde super plasticizer that conforms to GB8076-2008 [16] was obtained from the Longhui Manufacturing Company in Shaanxi and was used as received. It has a high molecular weight, long chain and sulfite group (-SO_3^{2-}) and a high water-reducing rate. The molecular weight of the super plasticizers is 2000–3000, their pH is eight and their moisture content is 4.2%. The fluidity of the cement paste is 210 mm, the water-reducing rate is 24.7% and the solid dosage of super plasticizer is 1–1.4% of the binder.

2.2.5. Concrete mix proportions

According to the technical specifications for application of the fly ash in concrete (GBJ 146-90) [17], an excess coefficient method was used to design the mix proportions of concrete containing CMA. The best concrete performance is achieved when 15% cement is replaced by CMA [18]. The concrete mixture proportions are shown in Table 2.

Table 1
Chemical composition and physical properties of Portland cement and CMA.

	Chemical composition (wt.%)										
	SiO_2	CaO	Al_2O_3	K_2O	Fe_2O_3	MgO	C	SO_3	Na_2O	P_2O_5	Loss ignition
Cement	47.6	9.17	27.0	1.93	4.97	1.08	4.30	1.29	0.72	0.32	0.75
CMA	53.1	13.4	8.75	4.96	3.54	3.23	5.78	2.50	0.76	2.79	4.69
CMA-M	54.8	15.1	8.67	5.17	3.59	3.22	2.55	2.09	0.73	3.03	4.39
CMA-U	55.6	15.6	9.18	5.10	3.79	3.30	0	2.41	0.878	3.05	11.12

Physical properties	Packing density (g/cm^3)	Specific surface (cm^2/g)	Color (%)
Cement	1.875	3870	Gray (50), black (50)
CMA	0.351	5572	Gray (40), black (60)
CMA-M	0.362	4391	Gray (80), black (20)
CMA-U	0.382	4056	White (80), red (20)