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The relevance of ultrafine fly ash properties and mechanical properties in its fly ash-cement gelation blocks via static pressure forming

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HIGHLIGHTS

- The ultrafine grinding of fly ash resulted in not only the decrease of their particle sizes, also the decrease of crystallinity degree and the anion polymerization degree of silicates and aluminates.
- The enhancement of CFBFA in producing C-S-H was greater at its early age but lower at its late age than those of PCFA.

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ABSTRACT

Two fly ash samples, collected from the circulating fluidized bed (CFBFA) and pulverized boiler (PCFA) were ultrafine grinded and characterized by the scanning electron microscopy (SEM), the X-ray diffractometer (XRD) and the fourier transform infrared spectroscopy (FT-IR). The characterizations revealed the ultrafine grinding of fly ash resulted in not only the increase of their specific surface areas, also the decrease of crystallinity degree and the anion polymerization degree of silicates and aluminates. In comparison to CFBFA, PCFA showed a higher anion polymerization degree of silicates and aluminates. This was followed by strength behavior studies of the fly ash-cement gelation blocks. The mixing ratio of tested fly ash and cement was 1:1 (by wt%), and the fly ashes included those before and after ultrafine grinding. The results showed that ultrafine fly ash (UFFA)-cement blocks exhibited higher compressive strength as compared to that of original fly ash (OFA)-cement blocks, especially at their early stage. Compared with PCFA, CFBFA was more significant in improvement of mechanical properties of fly ash-cement block at its early age for the gelation block. Studies on the water absorption and the thermal weight loss revealed the effectiveness of UFFA in increasing the density and producing more C-S-H in order to improve the mechanical properties in gelation blocks. Due to the difference of CFBFA and PCFA in chemical and mineral compositions, the enhancement of CFBFA in producing C-S-H was greater at its early age but lower at its late age than those of PCFA.

1. Introduction

Fly ash is solid waste products derived from the coal combustion. There are two major coal combustion boilers, generating pulverized coal fly ash (PCFA) and circulating fluidized bed fly ash (CFBFA), respectively [1–2]. Each year in China, the estimated productions of PCFA and CFBFA are more than 300 and 280 million tons, respectively. The accumulated of the total fly ash has been so far more than 2500 million tons [2–5], not only occupying the land, also causing environmental pollutions. Therefore, efforts must be taken on the utilization of fly ash in large scale. Currently, More than 80% of fly ash has partially replace the cement to prepared industrial building products world-wide [4–8]. Its potential as industrial building materials is because of its pozzolanic activity [9–12], by which SiO_2 and Al_2O_3 in fly ash can react with the calcium hydroxide (C-H) during cement hydration to form the hydrated calcium silicate (C-S-H) and hydrated calcium aluminate (C-A-H). Both can contribute to the strength improvement [13]. But Because of their different physiochemical properties, the CFBFA is different from the PCFA in their pozzolanic activities [14–15]. This determines their different utilization in terms of building materials.

The utilization of fly ash as industrial building material has been studied extensively. The major focus is on the solutions toward the strength enhancement at the early curing stage and the durability improvement of the building products containing fly ash [16–18].

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Many studies indicated that the finer the fly ash, the much better the improvement of the strength and the long-term durability [19–24]. This is mainly attributed to the destruction of the network structure of fly ash by mechanical force in the ultrafine grinding process, resulting in the breakdown of chemical bonds such as Si-O, Al-O [25]. A large amount of metastable active sites in the fractured surfaces of Si-O and Al-O can be beneficial for accelerating the pozzolanic reaction to form the more gel-like C-S-H structure. Furthermore, ultrafine fly ash (UFFA) helps the structure densification and the strength enhancement of construction products. Shaikh et al. [26–27] studied the effect of UFFA on mechanical properties of high volume fly ash mortar, and found the increase of the compressive strength of cement mortars by about 27% in the 8% UFFA replacement. Partha et al. [28] studied the addition of UFFA on setting, strength and porosity of geopolymer paste specimens cured at 20 °C, and found that the addition of UFFA lead a reduction in porosity and a denser microstructure of geopolymers and reduced setting times and improve compressive strength of geopolymers. Zhao et al. [29] observed similar results. Paya et al. [30] calculated the compressive strength gain and the pozzolanic effectiveness ratio, clarifying the increased pozzolanic activity with grinding of fly ash. Chindaprasirt et al. [31] comparatively studied the concrete microstructure of the portland cement and the replacement by original fly ash and fine fly ash, respectively. It showed that the incorporation of classified fly ash significantly decreased the pore sizes of blended cement paste, and the properties of fly ash were obviously improved after ultrafine treatment to enhance the mechanical behavior of products. However, few studies focused on the comparison in changes of CFBFA and PCFA before and after ultrafine grinding and their effects on mechanical properties in its fly ash-cement gelation blocks via static pressure forming.

This study detailed characterized particle size distribution and specific surface area of CFBFA and PCFA during ultrafine grinding, and their effects on properties of its fly ash-cement gelation blocks via static pressure forming, in terms of their compressive strength and water absorption. Microscopic properties and pozzolanic activity level of CFBFA and PCFA before and after ultrafine grinding were characterized using the scanning electron microscopy (SEM), the X-ray diffractometer (XRD) and the fourier transform infrared spectroscope (FT-IR). The contents of C-S-H in fly ash-cement blocks were determined by the thermogravimetric analyzer (TGA).

Table 1
Chemical composition of raw fly ashes (%wt).

	PCFA	CFBFA	Cement
SO_3	0.2	4.59	2.94
SiO_2	52.7	39.46	25.46
CaO	3.7	9.79	52.09
MgO	1.2	2.17	3.34
Fe_2O_3	9.7	4.77	2.55
Al_2O_3	25.8	35.67	9.28
K_2O	1.64	0.47	0.68
Na_2O	0.71	0.13	0.85

2. Experimental

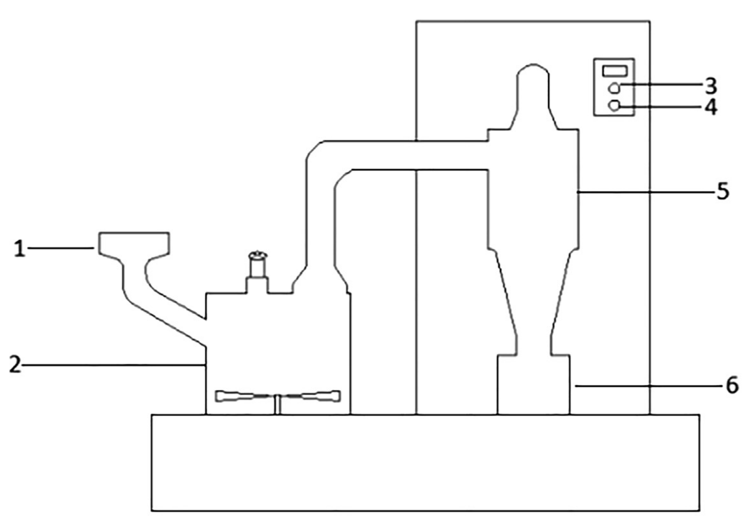
2.1. Raw materials

The experimental raw materials included two kinds of fly ash, one was CFBFA collected from a coal gangue circulating fluidized bed power plant in China, and the other was PCFA collected from a pulverized coal power plant in china. The commercially available P.O32.5 ordinary Portland cement was used as a base material. The chemical analysis of the raw materials was listed in Table 1.

2.2. Grinding

The two kinds of fly ash were ultrafine grinded by ultrafine grinder (TLB-4008), as shown in Fig. 1. The grinding process followed a procedure as, 1) confirming the tight close of the grinding chamber, starting the grinder and adjusting its rotation speed to 30 Hz, and 2) loading raw fly ashes slowly into the rotating grinding chamber from the hopper and grinding fly ash under mechanical force generated by the high-speed rotating grinding wheel, and 3) after grinding, blowing the ultrafine fly ash particles into the cyclone collector to be collected for future studies. The loading amount of fly ash in each grinding test was 3 kg, and the grinding time was 60 min to get more ultrafine fly ash.

Original circulating fluidized bed fly ash (O-CFBFA), original pulverized coal fly ash (O-PCFA), ultrafine circulating fluidized bed fly ash (UF-CFBFA) and ultrafine pulverized coal fly ash (UF-PCFA) were mixed with cement respectively in a mixer for 2–3 min. The mass ratio of mixture was 1: 1, the ratio was referenced to Chinese National Standards GB/T 12957-2005. This was followed by the addition of 18% water into the mixture and



1 Hopper; 2 Grinding chamber; 3 Switch; 4 FM; 5 Blower; 6 Cyclone collector

Fig. 1. The schematic of the ultrafine grinder.