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Characterization of sintered coal fly ashes

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Abstract

Çan, Çatalağzı, Seyitömer and Afşin-Elbistan thermal power plant fly ashes were used to investigate the sintering behavior of fly ashes. For this purpose, coal fly ash samples were sintered to form ceramic materials without the addition of any inorganic additives or organic binders. In sample preparation, 1.5 g of fly ash was mixed in a mortar with water. Fly ash samples were uniaxially pressed at 40 MPa to achieve a reasonable strength. The powder compacts were sintered in air. X-ray diffraction analysis revealed that quartz (SiO_2), mullite ($Al_6Si_2O_{13}$), anorthite ($CaAl_2Si_2O_8$), gehlenite ($Ca_2Al_2SiO_7$) and wollastonite ($CaSiO_3$) phases occurred in the sintered samples. Scanning electron microscopy investigations were conducted on the sintered coal fly ash samples to investigate the microstructural evolution of the samples. Different crystalline structures were observed in the sintered samples. The sintered samples were obtained having high density, low water adsorption and porosity values. Higher $Al_2O_3 + SiO_2$ contents caused to better properties in the sintered materials.

Keywords: Coal fly ash; Recycling; Sintering

1. Introduction

The sintering process is a world wide known technique in the production of conventional ceramic materials. Sintered ceramics have been widely used in the construction sector. The ceramic industry consumes large quantities of natural raw materials such as quartz, feldspar and clay. A ceramic factory of medium size uses ~400 tonnes of natural raw materials per day [1]. It is necessary to supply high amounts of raw materials to this industry. Therefore, research should be done to explore alternative raw materials for the ceramic industry, considering the large quantities of raw materials needed for ceramic production and the conservation of the natural sources.

Increasing demands to the generation of more electric power has resulted in construction of coal fired thermal power plants worldwide and thus of coal consumption and generation of the combustion wastes. In Turkey, considerable amounts of coal fly ash are generated daily in the thermal power plants, due to the high coal consumption and the high mineral matter content of coal. Fly ash's potentially hazardous nature is primarily due to the volatile toxic metals that it contains and therefore, it causes environmental pollution. The management of coal fly ash is a major problem in Turkey since only a small amount of it is utilized. Fly ash contains valuable oxide resources such as SiO_2, Al_2O_3, CaO, Fe_2O_3, and other oxides. These oxides have been mainly considered as a low cost material resource for the ceramic industry. Moreover, fly ash is presented as a fine dust so it can be directly incorporated into ceramic pastes, with almost no pre-treatment. Therefore, coal fly ash is a good candidate for the ceramic industry as a raw material resource. However, ceramic materials must be produced from fly ash without any additives. Otherwise the production would be unjustified economically and the aim of reducing environmental pollution would not be achieved [1]. Many researchers have investigated the production of ceramics from coal fly ash with the addition of natural raw materials and wastes such as

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quartz, clay, alumina, talc, titanium and tincal ore waste [1–8].

In this study, coal fly ash samples obtained from four different thermal power plants have been sintered using conventional powder processing based on powder compaction and firing, without the addition of any additives. The main aim of this investigation is to optimize a powder technology route for fly ash samples in order to maximize the sintered density of the products with the lowest possible sintering temperature.

2. Experimental procedure

2.1. Starting materials

The fly ash samples used in this study were obtained from Çan, Çatalağzı, Seyitömer and Afşin-Elbistan thermal power plants in Turkey. Chemical compositions and loss of ignition values of fly ash samples are given in Table 1 [9].

It is clear that the major chemical components in fly ash samples are SiO_2, Al_2O_3, CaO. The amount of SiO_2–Al_2O_3–CaO varied in the range of 63.54–82.67% while the amounts of MgO–Na_2O–K_2O varied in the range of 4.32–9.8%. The chemical composition of fly ash samples, except Afşin-Elbistan fly ash, is suitable for the ceramic production. SiO_2 content of Afşin-Elbistan fly ash sample is so low as a raw material used in the ceramic production. The amount of Fe_2O_3 in Seyitömer fly ash sample is more than the other fly ash samples and it was reported that the high iron content of the fly ash sample negatively affected the final properties of the ceramic materials [1].

The average particle sizes were determined using a Shimadzu centrifugal particle size analyzer (SA-CP3 Model) and the density of fly ash samples were determined by means of mercury porosimeter. Particle size and the densities of fly ash samples were obtained in a previous study [9]. As seen from Table 2 particle size of fly ash samples varied in a wide range. The particle size distributions of Çan, Çatalağzı and Afşin-Elbistan fly ash samples show a major fraction (40–60)% in the range of 20–50 μm. The upper size limit is 300 μm and 25% of the particles in fly ash samples are smaller than 10 μm. Çan, Çatalağzı, and Afşin-Elbistan fly ash samples are in a fine powder form. Most of the particles in Seyitömer fly ash are (50–60)% in the range of 200–300 μm. The upper size limit is 800 μm and 20% of the particles are smaller than 50 μm. Particle size of Seyitömer fly ash sample was bigger than the other fly ash samples. Density of fly ash samples ranged from 1.69 to 2.03 g/cm^3.

Table 2
Average particle sizes and densities of the waste materials [9]

Waste materials	Density (g/cm^3)	Average particle size (μm)
Çan fly ash	1.69	29
Çatalağzı fly ash	1.72	12
Seyitömer fly ash	1.73	261
Afşin-Elbistan fly ash	2.03	57

X-ray diffraction (XRD) was utilized to determine the mineralogical properties of the fly ash samples. During the combustion process, temperature may exceed 1600 °C. This temperature is sufficiently high to melt most of the inorganic materials present in the fly ash samples. The majority of the minerals formed were quartz, anorthite, mullite and enstatite. Table 3 shows the mineralogical composition of fly ash samples [9]. As seen from Table 3, Seyitömer fly ash sample contains hematite phase in addition to other phases present in all fly ash samples, due to high Fe_2O_3 content of it.

2.2. Preparation of sintered materials from fly ash samples

In sample preparation, a small amount of water was used to wet fly ash before compaction. 1.5 g of fly ash was mixed in a mortar with water at the water/solid ratio of 0.1 for each pellet. Fly ash samples were uniaxially pressed at 40 MPa as the circular pellets of 10 mm diameter. The powder compacts were sintered in air. Firing experiments were carried out in the Protherm PLF 1600 furnace equipped with a small chamber and a programmable controller (the internal PID constants were adjusted to obtain a maximum deviation of 7 °C). Before every sintering operation the samples were pre-heated to 300 °C for 60 min to derive off adsorbed gases and moisture. After this, the temperature was raised to the firing temperature. The heating rate was 10 °C/min and the sintering time was 120 min for all samples. All samples were cooled down in the furnace.

2.3. Characterization of the sintered samples

2.3.1. Microstructural characterization

The sintered samples were analyzed by means of X-ray diffraction to determine which crystalline phases were present and also to determine if the sample had fully crystallized. In all cases, samples were ground to fine powder form and

Table 1
Chemical analysis of fly ash samples [9]

Waste materials	SiO_2 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	Fe_2O_3 (%)	Na_2O (%)	K_2O (%)	SO_3 (%)	LOI (%)
Çan fly ash	49.07	30.80	1.46	2.46	6.13	0.63	3.86	4.20	0.83
Çatalağzı fly ash	48.88	27.63	6.16	2.71	6.68	0.45	2.39	3.55	1.41
Seyitömer fly ash	44.58	22.54	6.76	8.98	9.85	0.22	0.60	2.52	3.83
Afşin-Elbistan fly ash	18.11	7.63	37.80	3.50	5.23	0.22	0.60	18.22	8.40