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Physical, chemical, mineralogical, and thermal properties of cenospheres from an ash lagoon

P.K. Kolay, D.N. Singh*

Department of Civil Engineering, Geotechnical Engineering Division, Indian Institute of Technology, Bombay, Powai, Mumbai 400 076, India

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Abstract

A small percentage of the particles, present in the pulverized coal ash, consists of thin-walled hollow spheres or cenospheres. Their quantity depends on the carbon and iron contents present in the ash. The apparent density of these cenospheres is less than that of water and as such, they float on the ash slurry when it is impounded in the ash ponds or lagoons. Cenospheres are being used in different industrial applications, mainly due to their low density, high strength, and good thermal properties. However, it is important and mandatory to study and characterize these ash particles for a better and effective usage. As such, an effort has been made in this paper to study physico–chemico–mineralogical and thermal properties of the cenospheres obtained from an ash lagoon.

Keywords: Cenospheres; Chemical composition; Mineralogical composition; Particle size; Thermal properties

1. Introduction

The word ‘cenosphere’ is derived from two Greek words, *kenos* (hollow) and *sphaira* (sphere) [1]. Cenospheres are lightweight, inert, and hollow spheres mainly consisting of silica and alumina, are filled with air or gases, and are by-products of the combustion of pulverized coal at the thermal power plants. These ash particles get their hollow spherical shape as a result of cooling and solidifying around a trapped gas (generally CO_2 and N_2 bubble) from the molten droplets of inorganic coal residue. Another variety of the particles, present in the coal ash, is the particle containing included spheres (hollow or solid) and is called ‘plerosphere’ [2].

The amount of cenospheres or plerospheres in an ash normally depends on its carbon and iron contents. In general, the diameter of cenosphere ranges from 20 to 200 μm; density varies from 0.3 to 0.6 g/cm^3; and shell wall thickness varies from 2 to 10 μm [1]. Due to their hollow structure, these ash particles float on water when ash is disposed in the slurry form, in ash ponds, or lagoons. Due to their low density, high strength, good thermal and electrical capacities, and good tolerance for chemical agents and high temperatures, cenospheres find tremendous application in various industries [3–5].

However, before using cenospheres for any of these industrial or commercial applications, their properties must be studied in detail. This calls for characterizing their physico–chemico–mineralogical and thermal properties. As such, an effort has been made in this paper to characterize cenospheres obtained from a thermal power plant located in India.

2. Experimental investigations

The floating material on the ash lagoon of Bombay Suburban Electric Supply (BSES), Dahanu Thermal Power Plant, Maharashtra, India has been collected. This sample is mixed with water and is centrifuged (at 4000 rpm) for a period of 30 min. Later, the material floating on the water surface has been filtered and oven-dried. The following tests have been conducted to characterize this sample (of cenospheres).

2.1. Chemical composition

The chemical composition of the sample has been obtained with the help of an X-ray fluorescence (XRF) setup (Model No. Phillips 1410, Holland).

* Corresponding author. Tel.: +91-022-576-7340; fax: +91-022-576-7302.

E-mail address: dns@civil.iitb.ernet.in (D.N. Singh).

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Table 1
Chemical composition (wt.%) of the cenosphere sample

Elements	wt.%
SiO_2	52.53
Al_2O_3	30.01
Fe_2O_3	7.53
CaO	1.15
SO_3	0.02
Na_2O	0.02
K_2O	1.98
MgO	0.32
TiO_2	1.79
P_2O_5	0.45
Loss on ignition	4.20

2.2. Mineralogical composition

The sample has been evaluated for its mineralogical composition by X-ray diffraction (XRD) spectrometer (Phillips), with graphite monochromator and Fe $K\alpha$ radiation. The sample is scanned from 2θ of 0–80°. The search match JCPDS data files have been used for identification of the minerals present in the sample.

2.3. Particle size distribution

Dry sieving [6] and a laser particle size analyzer, Galai CIS-1, Japan, have been employed to study the particle size distribution of the sample.

2.4. Specific gravity

The specific gravity of the sample has been obtained [7] by conducting a series of three tests and selecting two consecutive similar values.

2.5. Specific surface area

The specific surface area of the sample has been determined [8] with the help of Blaine's air permeability apparatus. For standardization, the Portland cement has been taken as the reference material. The specific surface area (S) of the sample has been obtained with the help of Eq. (1):

$$S = [S_s(1 - e_s)\sqrt{e^3}\sqrt{T}]/[\sqrt{e_s^3}\sqrt{T_s}(1 - e)] \quad (1)$$

Where, S_s is the specific surface area of the Portland cement (=3460 cm^2/g), e and e_s correspond to the void ratios of the cenosphere sample and the cement (=0.5), respectively. T_s and T are the times required by air to pass through the samples of cement (=77.18 s) and cenosphere, respectively.

2.6. Thermogravimetric analysis (TGA)

TGA of the cenosphere sample has been conducted by using thermal analyzer (Model DT 30, Shimardzu, Japan). Dry air atmosphere has been used for TGA analysis. Approximately 10–15 mg of the sample has been taken for the analysis. The rate of heating has been maintained to 10°C/min and the cenosphere sample is heated up to 900°C.

2.7. Differential thermal analysis (DTA)

DTA of the cenosphere sample has been conducted by using the thermal analyzer (Model DT 30, Shimardzu). The analysis has been carried out with the same conditions mentioned in Section 2.6.

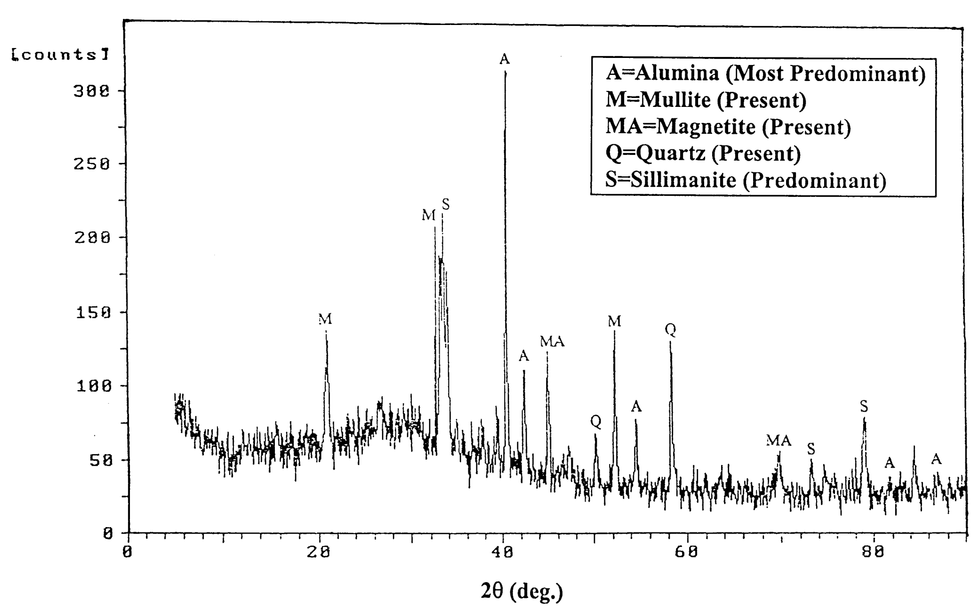

Fig. 1. X-ray diffraction pattern for the cenosphere sample.

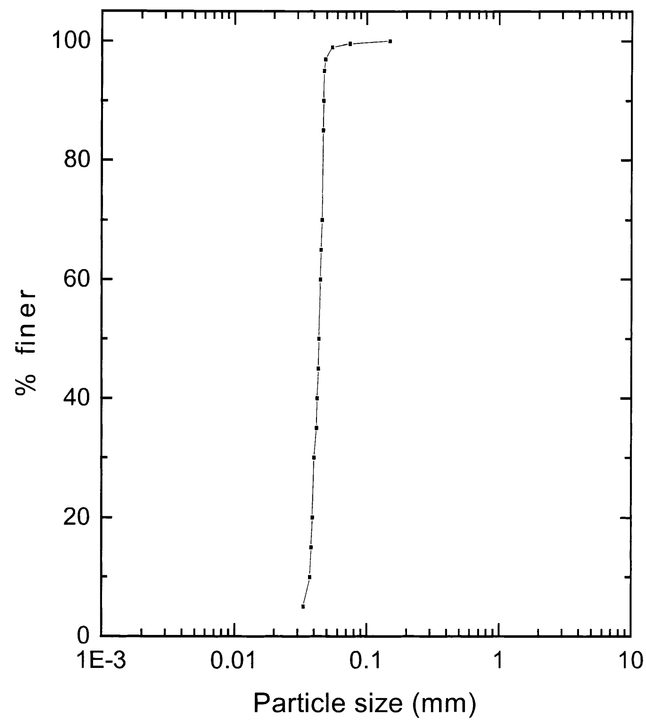

Fig. 2. Particle size distribution characteristics for the cenosphere sample.

2.8. Scanning electron microscope (SEM)

To study the morphology of the cenosphere particles, SEM, JEOL, JSM 840A (Japan), has been used.

3. Results and discussion

Results of the tests conducted, and mentioned above, on the cenosphere sample are being presented in the following.

The results of XRF study are presented in Table 1. It can be noticed that for the cenosphere sample, the percentage of SiO_2, Al_2O_3, and Fe_2O_3 is 52.53%, 30.01%, and 7.53%, respectively.

Fig. 1 shows the X-ray diffraction pattern of the cenosphere sample. From the figure, presence of alumina, sillimanite, mullite, and magnetite can be noticed. However, alumina is the most predominant mineral present in the cenosphere sample.

Fig. 2 presents particle size distribution of the cenosphere sample obtained from dry sieving and using a laser particle size analyzer. From Fig. 2, it can be noticed that the cenosphere sample consists of particles (in majority) with diameter ranging from 0.03 to 0.055 mm. However, few particles with maximum diameter of 0.150 mm are also noticed in the sample.

The average specific gravity of the cenosphere sample is found to be 0.78, which is less than that of water; as such, the cenosphere particle floats on water when the ash is disposed into the lagoons or ash ponds.

The specific surface area of the cenosphere, calculated by using Eq. (1), was found to be 457 cm^2/g. This is very much less than that observed for the ash generally collected from electrostatic precipitator. This may be attributed to the fact that the cenospheres are perfect spheres and are uniform in size, so the interstitial space between the cenosphere particles is generally more and subsequently the surface area is less.

Fig. 3 depicts SEM micrographs of the cenosphere sample. From these micrographs, it can be noticed that the cenosphere sample consists of almost regular spherical particles, ranging from 0.040 to 0.14 mm in diameter. This is noticed to be in good agreement with the particle size distribution characteristics depicted in Fig. 2.

Fig. 4 presents the TGA of the cenosphere sample. It can be noticed from Fig. 4 that the loss in weight has taken place with the increase of temperature. At approximately 300°C, the weight loss undergone by the sample is $>90\%$. This may be attributed to the fact that high temperature is responsible for the expulsion of the air, or gas, entrapped in the cenospheres. However, the DTA (Fig. 4) indicates

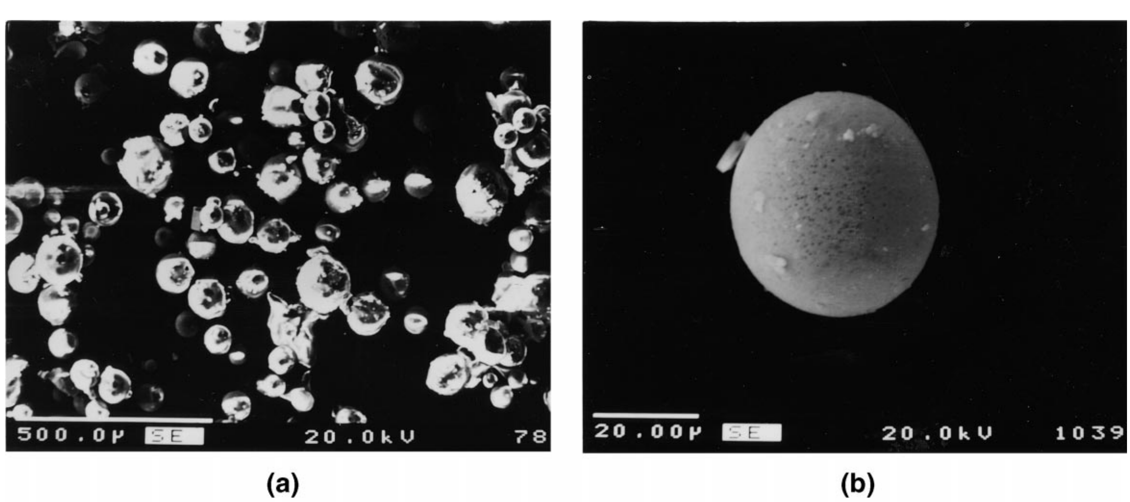

Fig. 3. SEM micrographs for the cenosphere sample.

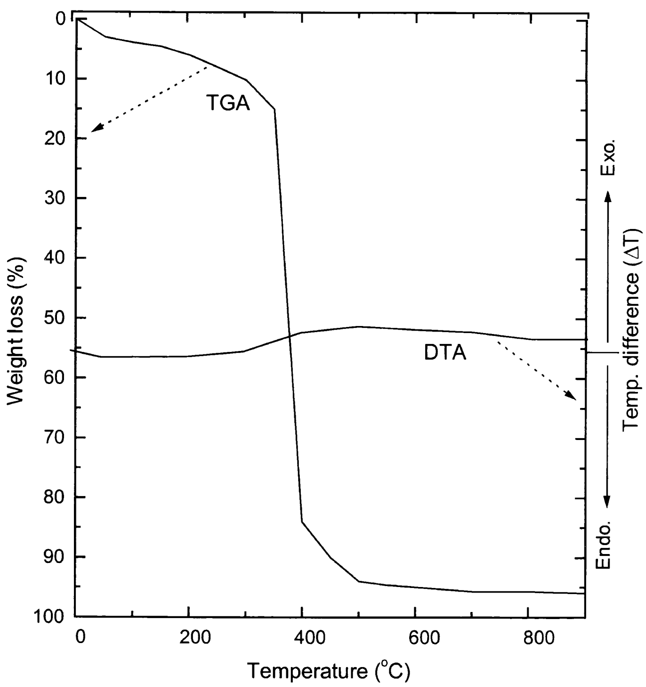

Fig. 4. TGA and DTA patterns for the cenosphere sample.

formation of an endothermic peak at around 330°C. This may be attributed to the removal of water dissolved in glassy material of the cenosphere sample [1].

4. Conclusions

From the results and discussion mentioned above, the following generalized conclusions can be drawn:

1. The cenospheres are lightweight and their specific gravity is very low.
2. Alumina and quartz are the most predominant minerals present in the cenosphere sample.
3. These particles are noticed to be almost uniform in size and as such, the specific surface area of the cenospheres is quite low.
4. The cenosphere sample is noticed to be thermally stable up to a maximum of 280°C.

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