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THERMAL CHARACTERISTICS OF A CLASS F FLY ASH

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ABSTRACT

It is necessary to evaluate thermal properties of geotechnical materials, viz. soils and rocks, for power cables and oil pipe lines and disposal of nuclear wastes. A situation may arise where the heat dissipation through the soils and rocks may not be satisfactory, leading to adoption of a backfill. Fly ash can be used in conjuction with aggregates to design a proper backfill material. The thermal characteristics of this material, in terms of its resistivity, play an important role in the design of a thermally stable backfill, i.e., Fluidized Thermal Backfill (FTB). As such it is desired to establish thermal response of the fly ash based on its physical and moisture- holding characteristics. In this paper an effort has been made to evaluate the thermal resistivity of a Class F fly ash using a laboratory thermal needle/probe. The effect of density of compaction and the moisture content on the thermal response of the fly ash has been also studied. © *1998 Elsevier Science Ltd*

Introduction

Thermal properties of materials are important for various engineering projects, ranging from those of man-made materials such as insulation, to those of natural materials such as soil, which is significant in view of the modern trends of utilizing the subsurface for several purposes such as burial of high voltage electric power cables (1), storage and containment of radioactive spent fuel (2,3), burial of pipelines for the conveyance of high-temperature liquids (oil pipes and steam pipes), and utilization of earth energy for space heating/cooling via ground-coupled heat pumps (4,5). For these situations, thermal characteristics of the material, such as the thermal resistivity and the thermal stability, must be known.

Soil as such is not a good conductor of heat when compared to the metals (normal conductors). Soil thermal resistivity is a measure of the resistance offered by the soil to the passage of heat. Thermal stability is normally related to the ability of moist soil to maintain a relatively constant thermal resistivity when subjected to an imposed temperature difference. Thermal instability occurs when a soil is unable to sustain a rate of heat transfer; to overcome this, the native soil is replaced by materials (backfills) with better thermal properties. Fly ash, mixed with sand and aggregates, can be used as a good backfill material, called Fluidized

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Thermal Backfill (FTB) (2), to maintain thermally stable conditions. It is essential to access the thermal behaviour of fly ash before it is utilized as an backfill material.

In this paper, the thermal characteristics of a class F fly ash have been evaluated using the laboratory thermal probe.

Principle of Operation

For the sake of completeness, the principle of operation is presented in the following. A thermal needle (or a Probe) approximates a line source of heat input of Q per unit length, of constant strength, in an infinite homogeneous soil medium maintained at uniform temperature, initially. Temperature at any point in the soil medium depends on several variables, the important ones being duration of heating (time) and the soil thermal conductivity. In the mathematical form the same can be presented as (6):

$$\frac{\partial \theta}{\partial t} = \alpha\left(\frac{\partial^2 \theta}{\partial r^2} + \frac{1}{r}\frac{\partial \theta}{\partial r}\right) \tag{1}$$

where θ is the temperature of the soil mass, t indicates the time of heating, α is the thermal diffusivity constant ($=k/\gamma \cdot Cp$), k represents the thermal conductivity of the soil, Cp is the specific heat of the soil, γ represents the unit weight of the soil, and r is the radial distance from the heat source.

Thus the temperature rise, $\Delta\theta$, between the time interval t_1 and t_2 may be represented as:

$$\Delta\theta = \left(\frac{Q}{4\pi k}\right)\log_e\left(\frac{t_2}{t_1}\right) \tag{2}$$

As such, plot of temperature against log of time shows a straight portion of slope $\left(\frac{Q}{4\pi k}\right)$. It will be noted that the average property of the body entering this expression is the thermal coductivity, and that the other terms in Eq. 2 are quantities readily measurable with the thermal probe designed by the authors.

Test Setup

Based on the above-mentioned principle, a needle that is stiff enough to withstand the pressures generated either during the process of fly ash compaction in preparation of a sample, or for inserting it into the fly ash after making a sample at a particular density, was fabricated for thermal resistivity evaluation. Such an arrangement, as presented in Figure 1, has been termed a "laboratory thermal probe," which consists of insulated Nichrome heater wire (with resistivity equal to 0.1923 Ω/cm) inserted in a copper tube (14 cm long, external diameter of 2.5 mm). A thermocouple was attached on the surface of the tube as shown in the figure. The calibration of this probe has been done using a standard liquid glycerol with thermal resistivity equal to 349°C-cm/W. The thermal resistivity value of the glycerol as measured by using this probe is observed to be 357.52°C-cm/W, with a small deviation of only 2.4%.

A metal container (12.6 cm long, 10.1 cm diameter) was used to prepare fly ash samples corresponding to a particular density. A 3-mm diameter hole was drilled in the sample so as

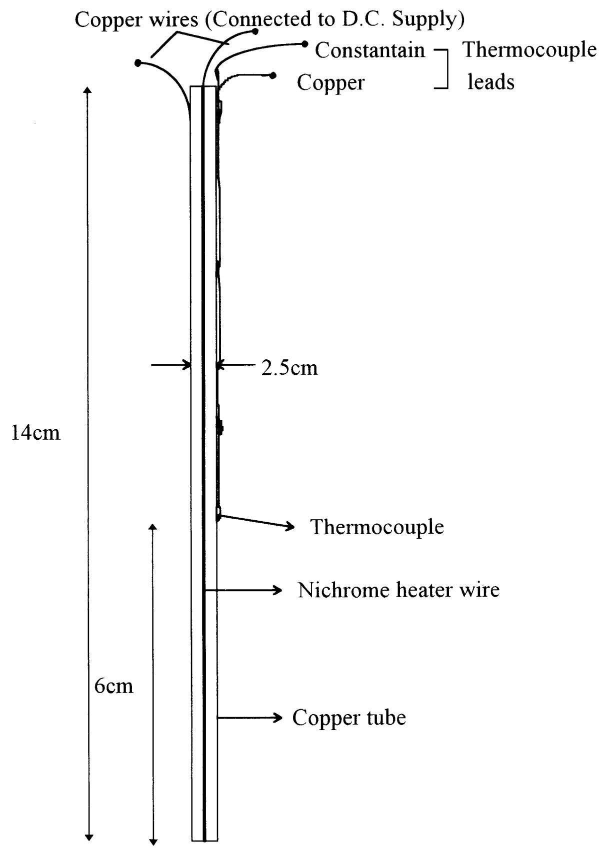

FIG. 1.
Details of the laboratory thermal probe.

to tightly fit the thermal probe into it. The probe was allowed to gain thermal equilibrium in the fly ash for some time (5 min. approx.) followed by switching on the controlled electrical power supply. The temperature of the probe was recorded as a function of time to compute thermal resistivity of the fly ash as discussed earlier.

Properties of the Fly Ash

Fly ash from Koradi Thermal Power Plant in Nagpur (India) has been taken for the present study. It is a light grey powder with specific gravity equal to 2.14. The particle size analysis has been conducted using a laser particle analyzer. It is noticed that the fly ash sample consists of about 90% silt (2–75 μm) with 10% clay (<2 μm).

Chemical Composition

The chemical composition (by percentage weight) is presented in Table 1.

TABLE 1
Chemical composition of the fly ash.

SiO_2	59.89%
Al_2O_3	27.20%
Fe_2O_3	4.33%
CaO	1.01%
MgO	1.53%
SO_3	0.03%
Na_2O	0.06%
K_2O	0.93%
MnO_2	0.08%
TiO_2	2.30%
P_2O_5	0.23%
Loss on Ignition	2.40%

Mineralogical Characterization

The fly ash sample has been evaluated for its mineral composition by scanning from 5–60° on a XRD spectrometer using Cu-Kα radiation. The minerals are identified by the Search Match JCPDS. The minerals present in the same are: Quartz low (syn)-most predominant, Mullite(syn)-predominant, Brookite, Sillimanite, and Ferroselite.

Compaction Characteristics

Standard Proctor compaction characteristics of the fly ash are presented in Figure 2.

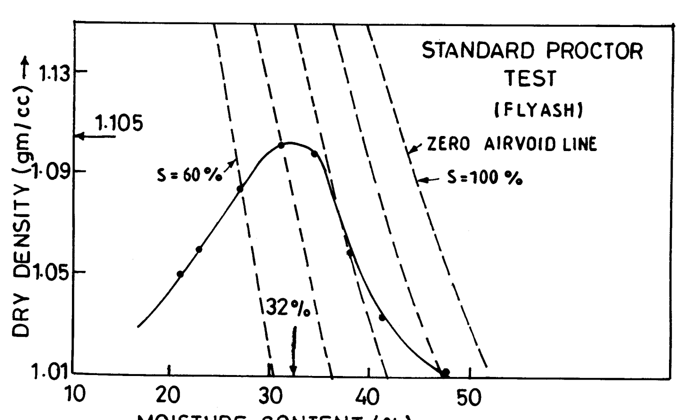

FIG. 2.
Standard Proctor compaction curve for the fly ash.

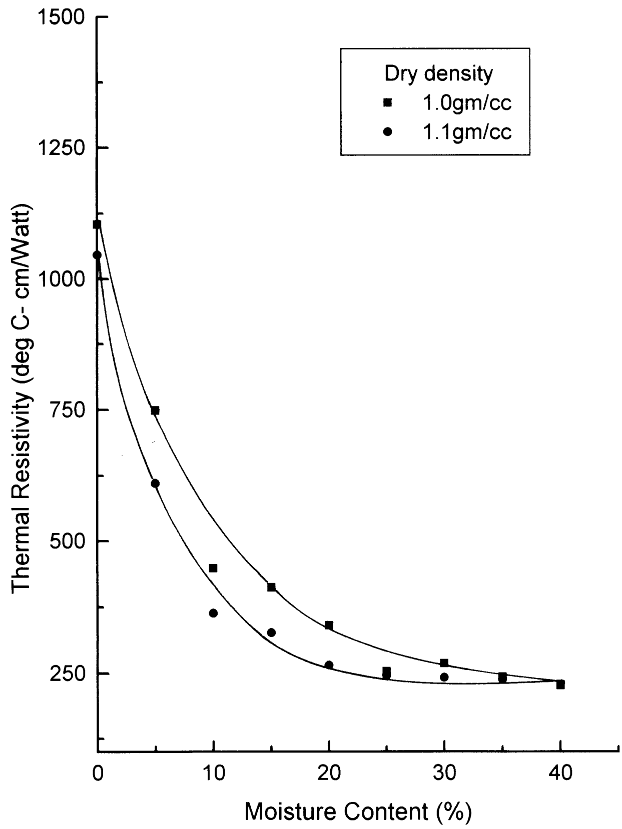

FIG. 3.
Thermal resistivity curve for the fly ash.

Results and Discussions

Tests have been conducted to obtain thermal resistivity of the fly ash with varying moulding moisture content for different density of compaction.

Figure 3 presents the thermal resistivity curves for the fly ash. From these curves it can be noticed that for dry state of the fly ash, the thermal resistivity value varies from 900°C-cm/W to 1150°C-cm/W with dry-density ranging from 1.0 to 1.1 gm/cc. With the addition of 5% moisture to the oven-dry fly ash, the thermal resistivity values drop to 600–750°C-cm/W. The drop in resistivity values continues up to almost 20% moisture content. However, this drop is much less as compared to the drop in the resistivity values for moisture content less than 10%. It can be noticed that the variation of thermal resistivity values in the moisture content range of 25 to 30% is almost negligible, and at 30% moisture content the fly ash exhibits lowest resistivity value (the range being 250 to 300°C-cm/W), which remains constant even with further addition of moisture. It is important to notice that minimum resistivity values are achieved close to the optimum moisture content of the fly ash (the same being 32%).

In general, from the resistivity-moisture content variations for fly ash (Fig. 3), it can be noticed that the resistivity of the fly ash decreases as its moisture content increases. The reason is that when water is added to the ash, it forms a thin film around the fly ash particles that eases the conduction of heat, i.e., incresasing its conductivity and reducing its resistivity. This may also be attributed to the fact that the thermal resistivity of air (equal to 4000°C-cm/W) is higher than that of the water (equal to 165°C-cm/W). The addition of water to the fly ash results in a decrease in the air voids (and hence the density increases), and as such the thermal resistivity of the fly ash in the near vicinity of its optimum moisture content (OMC) attains almost a constant value that is the minimum value of thermal resistivity the fly ash can exhibit. At this situation the resultant resistivity of the fly ash, known as "critical moisture content," is more dependent upon the resistivity of the pore water. There is a rapid increase in the thermal resistivity of the soil, with a small reduction in moisture content at moisture contents less than the critical moisture content. This critical moisture content depends on the particle size distribution and the density of compaction.

From the resistivity-moisture content variations, another important observation is that as compaction density increases, critical moisture content decreases. The range of critical moisture content values for fly ash as obtained in the present investigation is 28–32%.

Conclusions

Based on the results and discussions presented in the above, the following generalised conclusions can be made:

1. Resitivity of the fly ash decreases as the dry density increases. However, this effect is much more pronounced on the dry OMC as compared to the wet OMC.
2. The rate of decrease of resistivity is much more in the initial stage of moisture addition as compared to the moisture content close to the OMC. Close to the OMC the resistivity of the fly ash is minimal, and it remains almost constant, corresponding to the critical moisture content for the fly ash.

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