Use of Parawada Fly Ash as a Substitute to Soil in Embankments and Sugrades

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Abstract

Disposal of fly ash continues to pose serious problem in view of increasing quantities of fly ash produced as waste in thermal power plants and the increasing area required for its disposal every year in India and world over. The solution calls for bulk utilization of fly ash for civil engineering purpose. This paper presents the geotechnical characteristics of fly ash from NTPC, Parawada, India for its 100 percent utilization as a substitute for soil in embankments and subgrades. The study indicates that Parawada fly ash (PFA) shows a CBR of 13.99% under unsoaked conditions at OMC of 15.4% and MDD of 14.6 kN/m^3 under I.S. heavy compaction. The fly ash did not show any resistance under soaked condition. The grain size distribution, shear strength and permeability characteristics of PFA are also presented in this paper. The study also indicates that vibratory compaction is found to be less effective for fly ash under which it showed a dry density of 10.36 kN/m^3 as against 14.36 kN/m^3 under hammer blows of heavy compaction.

Keywords: *Parawada fly ash, waste utilization, soil, embankment, subgrade, heavy compaction, OMC, CBR.*

1. Introduction

Thermal power plants and other industries using coal as fuel continue to produce fly ash as waste in increasingly huge quantities in India and across the world (Vimal Kumar et al, 2005). This not only causes pollution of air, water and land but also spoils vast areas of useful agricultural lands as ash ponds (Sarat Kumar and Yudhbir, 2005). This has drawn the attention of Researchers across the world for increased utilization of fly ash as a useful material in Civil Engineering construction. The solution calls for high volume utilization of fly ash such as in concrete replacing cement (Narasinga Rao and Ananthasairam, 2017; Swapnil et al, 2016; Narasinga Rao, 2016; Aman et al, 2013; Binod Kumar et al, 2007; Toy Poole, 1995 etc.) and in embankments and subgrades substituting the soil (Narasinga Rao and Somasekhar, 2018; Vukićević et al, 2016; Sushant et al, 2015; Sridharan, 2012; Sungmin et al, 2009; Samrat & Chug, 2006; Pandian, 2004; Pandian et al, 2002 etc.).

In view of the growing need for development of road infrastructure in the country, conservative estimates show that about 15-20 MT ash can be used in construction of road and flyover embankments per annum in the vicinity of TPPs. This would yield a saving of around Rs. 100 crore per year (Aakash & Jain, 2015).

Fly ash has been classified into two types: Class F fly ash produced by burning older anthracite and bituminous coal and Class C Fly ash produced by burning of younger

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lignite or sub bituminous coal. The present study involves class F fly ash, which is more abundant than class C fly ash. For this study, fly ash has been obtained from NTPC, Parawada, Visakhapatnam district, Andhra Pradesh, India.

2. Literature review

Joseph et al (1990) reported that fly ash samples from three power plants in the Philadelphia-Wilmington-South Jersey area are poorly graded sandy silts with MDD of 10.0-13.0 kN/m^3 and OMC of 26-42 % under standard compaction. The permeability of compacted fly ashes was low (about 1.3×10^{-5} cm/s) which is environmentally favourable as seepage will move around a fly-ash body if there is an alternative path of lower resistance. They further argue that the strength property of major interest is the friction angle ϕ for fly ash as the apparent cohesion of unsaturated fly ash cannot be relied upon for long-term stability analysis. CBR of the fly ash was 10.8-15.4% in unsoaked condition which reduced to 6.8-13.5% upon soaking.

Pandian (2004) after reviewing the characteristics of several fly ashes across India concluded that fly ash is a freely draining material with angle of internal friction of more than 30° and that fly ash can be effectively utilized in geotechnical applications with some modifications/additives, if required.

Sarat Kumar Das and Yudhbir (2005) reported the grain size, specific gravity, compaction characteristics, and unconfined compression strength of both low and high calcium fly ashes, to evaluate their suitability as embankment materials and reclamation fills. They concluded that the geotechnical properties of fly ashes are governed by factors like lime content (CaO), iron content (Fe_2O_3), loss on ignition, morphology, and mineralogy.

Nine samples of class F fly ash, bottom ash and pond ash from Kolaghat, Budge Budge and Bandel thermal power plants have been used by Pal & Ghosh (2010) to study the suitability of using these materials for geotechnical construction.

Muhardi et al (2010) presented the characteristics of fly ash from Tanjung Bin power station, Malaysia and concluded that low specific gravity, freely draining nature, ease of compaction, good frictional properties, high shear strength and low compressibility can be gainfully exploited in the construction of embankments, roads, reclamation and fill behind retaining structures.

Sridharan (2012) underlined that the bulk use of coal ashes, having beneficial properties, in the field of geotechnical engineering, is an eco-friendly way of their safe disposal.

Gimhan et al (2018) studied the geotechnical characteristics of three fly ash samples from Norochcholai coal power plant, Sri Lanka and concluded that they are well graded sandy silts with low dry density of 12.36 kN/m^3 and high OMC of 33 % with cohesion of 26.4 kPa and friction angle of about 32.7°.

Earlier study by Narasinga Rao & Somasekhar (2018) indicates that Parawada fly ash can be mixed up to 60% with Thagarapuvalasa soil for use in embankments and subgrades with satisfactory geotechnical characteristics.

The present study uses 100% Parawada fly ash to examine its suitability as an embankment/ subgrade material. The present study assumes significance in view of the limited data available in using fly ash as a substitute to soil in embankment and subgrade in the widely consulted literature and also in view of the variability of fly ash characteristics in different thermal power plants as well as at different times within the same plant.

3. Methodology

Fly ash was collected from NTPC, Parawada from the ash silo of the plant. The following experiments have been conducted in the geotechnical engineering laboratory: 1) Wet & dry sieve analysis 2) Hydrometer analysis 3) LL & PL 4) Specific gravity 5) Differential free swell 6) IS Heavy compaction (Modified Proctor) 7) Direct shear test 8) CBR Test 9) Permeability test. All the tests have been done as per relevant Indian Standard Code (I.S.2720). Each test is conducted twice and the average of the values obtained from the two trials has been adopted. The % variation of the individual values from the average was observed to be marginal.

The fly ash sample has been washed through 75 μ I.S. sieve and the sample retained is oven-dried and subjected to dry sieve analysis. A separate sample passing 75 μ I.S. sieve is subjected to hydrometer analysis. The results of wet and dry sieve analysis and the hydrometer analysis are combined to generate the grain size distribution curve as shown in Fig.1.

The OMC and MDD of PFA have been determined on samples compacted at OMC. The direct shear test, CBR and the permeability tests have been conducted on PFA samples compacted at OMC. The CBR test has been conducted both under unsoaked and soaked conditions.

4. Results and discussion

4.1. Physical and index properties

Fig.1 shows the grain size distribution curve of Parawada fly ash (PFA). It consists of 65% silt, 25% sand, 10% clay and zero percent gravel. It is found to be Non-Plastic (NP) and Non-swelling (Differential free swell=0) and having a specific gravity of 2.08.

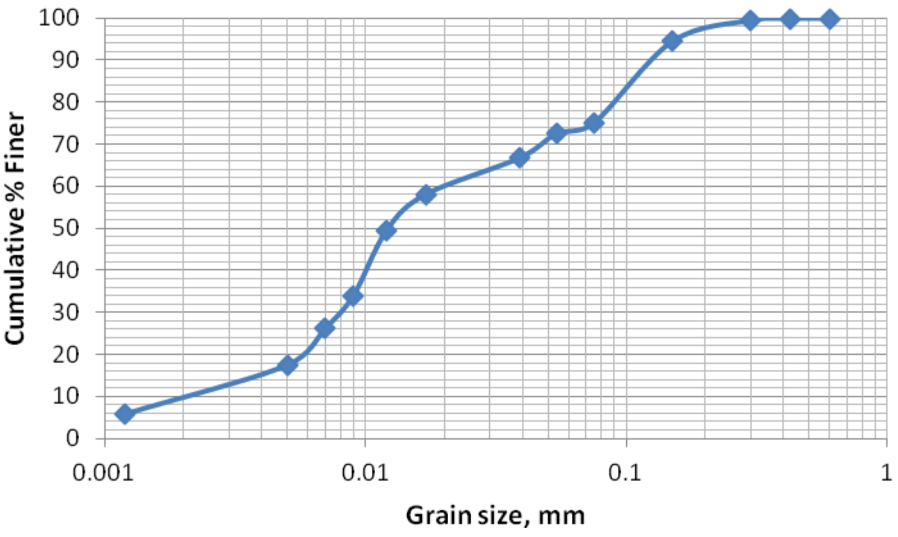

Fig. 1 Grain size distribution curve of PFA

4.2. Engineering characteristics

Fig.2 shows the water content-dry density relation for the PFA under I.S.Heavy compaction. The MDD obtained for PFA is 14.6 kN/m^3 at OMC of 15.4%. Unlike soils, the dry density of PFA is not significantly sensitive to water content, as can be seen from Fig.2.

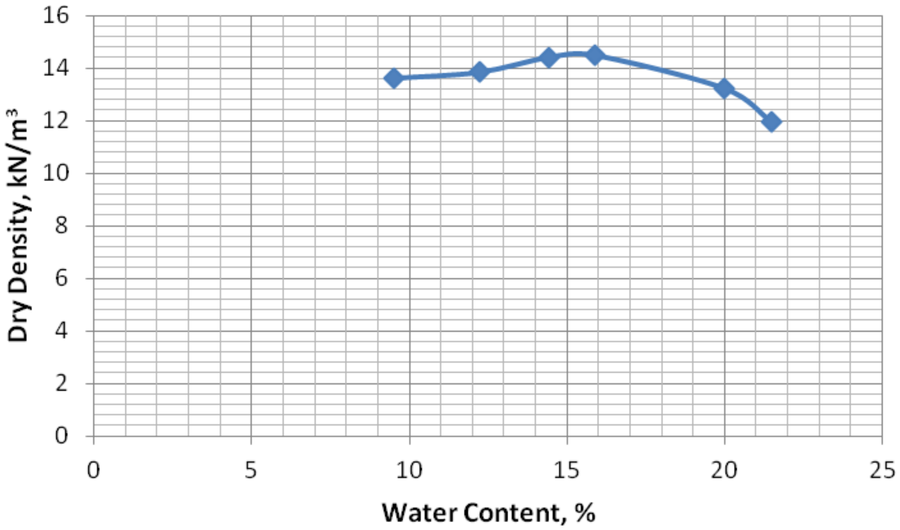

Fig.2 Compaction Curve for NFA

Direct shear test of PFA was performed with two trials. Fig.3 shows the normal stress-shear stress relation for the two trials, which shows that the strength envelope is non-linear in both trials. The strength envelope is steeper with higher friction angle up to a normal stress of 200 kPa and thereafter, it becomes nearly flat with negligible slope (friction angle) in both trials. In case of trial-2, the shear strength even decreases marginally when the normal stress is increased from 200 kPa to 400 kPa.

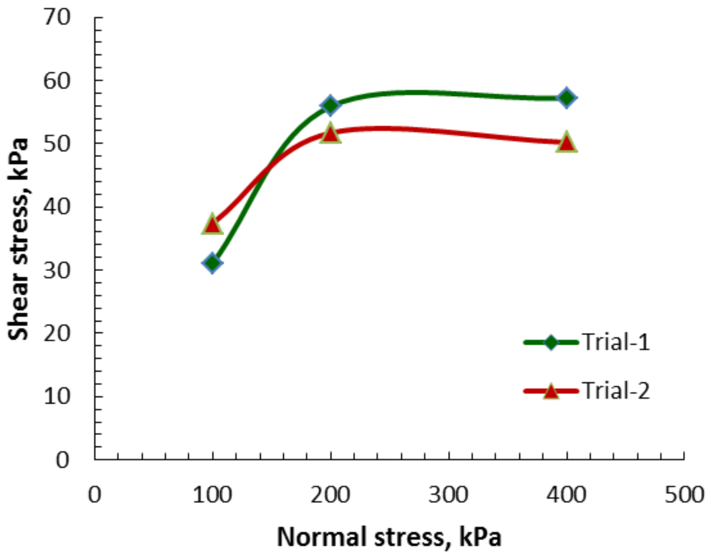

Fig.3 Normal stress–shear stress relation for PFA

Fig.4 shows the Best fit linear strength envelopes drawn for trial-1 (Green colour) and for trial-2 (Red colour). The Coulomb's strength equation for each trial is shown in the corresponding Trend line labels (coloured boxes in Fig.-4) along with correlation coefficients as obtained in MS Excel spreadsheet. The shear parameters obtained from these best fit strength envelopes are as follows:

Trial-1: c = 30.45 kPa and $\phi = 4.3°$

Trial-2: c = 38.15 kPa and $\phi = 2.03°$

It is evident that the linear strength envelopes have poor correlation coefficient in both trials. It is also debatable whether we can adopt such linear strength envelopes and the corresponding shear parameters, when the shear strength in reality becomes constant when the normal stress is greater than 200 kPa. Experience also shows the fly ash has reasonably good friction angle and poor cohesion.

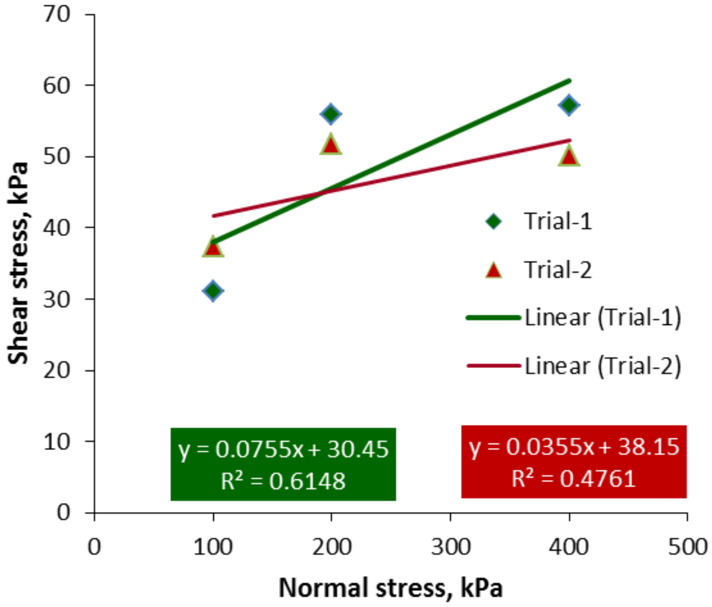

Fig.4 Linear Coulomb's strength envelopes for PFA

In the unsoaked CBR test of the PFA, the load penetration curve was concave upward and needed a zero correction. The unsoaked CBR determined from the corrected curve is found to be 18.2%.

The permeability of PFA was determined by falling head test and was found to be 2.05×10^{-5} cm/s, which falls in the range of permeability of dense sand and fine silt.

Dry PFA was used to conduct the standard Relative density test in the laboratory to verify the effectiveness of vibratory compaction. The maximum dry density of PFA obtained in the relative density test was 11.6 kN/m^3 as against I.S.Heavy compaction MDD of 14.6 kN/m^3. This indicates that vibratory compaction is not as effective as laboratory compaction for fly ash.

5. Conclusions

Following conclusions may be drawn based on the results obtained from the present study.

1) Fly ash can be used as a substitute for soil in embankments and subgrades as it has reasonably good unsoaked CBR and shear strength.
2) As fly ash shows poor resistance to penetration under soaked condition, the fly ash embankments need to be provided with a soil cover of suitable thickness at the top.

3) Fly ash embankments can be more effectively compacted using pneumatic tyred rollers than vibratory rollers as the latter yields less dry density than that in laboratory compaction.

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