Geotechnical Characteristics of HNPC Fly Ash

Narasinga Rao B. N. D., Suryanarayana Raju P.

***Abstract:** Fly ash is the solid waste being produced in largest quantities from thermal power plants in India causing pollution of land and water. It requires bulk utilization which is possible in geotechnical applications such as embankments and subgrades. This necessitates the determination of the geotechnical properties of fly ash from different thermal power plants. The present paper investigates the geotechnical characteristics of fly ash from HNPC, Pedagantyada, Visakhapatnam. The physical and index properties of HNPC Fly ash (HNFA) and its OMC and MDD using I.S. Heavy compaction are first determined. The shear strength, CBR and permeability are then determined at OMC. The study also investigates the influence of polyester fibers and lime as admixture to HNFA in different percentages on Compaction and CBR properties to check their effectiveness in improving HNFA for use in embankments and subgrade. The chemical and morphological characteristics of HNFA, including its specific surface, XRD, SEM and FT-IR spectra have also been determined. The study confirms the suitability of HNFA for use in geotechnical applications and verifies the relative suitability of polyester and lime as admixtures for further improvement of the geotechnical properties of HNFA.*

***Keywords:** Embankment, HNPC Fly ash, Lime, Polyester fibres, Subgrade, Waste utilization.*

I. INTRODUCTION

Nearly 73% of the total installed power generation capacity in India is thermal, of which, coal-based generation is about 90%. More than 85 thermal power stations, and several captive power plants use bituminous and sub-bituminous coal and produce large quantities of fly ash of over 200 million tons per annum.

The World Bank has cautioned India that by 2015, disposal of coal ash would require 1000 sq. km. of land. There is a need of new and innovative methods of utilizing fly ash for reducing impacts on the environment.

Fly ash can be used as a substitute to soil in structural fills for highways, buildings and other structures. The characteristics of fly ash vary with the thermal plants and with time within the same plant depending on the characteristics of the coal used and its combustion conditions.

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It is necessary to determine the geotechnical characteristics of fly ash from different thermal power plants, in order to facilitate engineers for large-scale utilization of fly ash in geotechnical engineering applications. Very limited studies have been carried out on the geotechnical properties of fly ash as observed in the widely consulted literature. Studies with polyester and lime as admixture to fly ash are even more limited.

The present study deals with the determination of geotechnical characteristics of fly ash from Hinduja National Power Corporation (HNPC), first without any admixture and then with polyester fibers and lime as admixture.

HNPC is located in Pedagantyada Mandal, about 20 km from Visakhapatnam. The plant was established in 2008 with total capacity of 1040 MW with two units producing 520 MW each. The current utilization of the fly ash is around 40%.

II. LITERATURE REVIEW

Reference [1] found 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. It is concluded that friction angle (ϕ), is the strength property of major interest for fly ash as its as the apparent cohesion in unsaturated condition cannot be relied upon for long-term stability. CBR of the fly ash was 10.8-15.4% in unsoaked condition which reduced to 6.8-13.5% upon soaking.

Reference [2], 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.

The grain size, specific gravity, compaction characteristics, and unconfined compression strength of both low and high calcium fly ashes have been evaluated by [3] for their suitability as embankment materials and reclamation fills. Reference [4] used samples of class F fly ash, bottom ash and pond ash from Kolaghat, Budge Budge and Bandel thermal power plants to study the suitability of using these materials for geotechnical construction.

Reference [5] presented the characteristics of fly ash from Tanjung Bin power station, Malaysia, and concluded that specific characteristics of fly ash such as low specific gravity, freely draining nature etc., can be gainfully exploited in the construction of embankments, roads, reclamation and fill behind retaining structures.

Reference [6] 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.

Reference [7], from their study of fly ash samples from Norochcholai coal power plant, Sri Lanka, observed that these samples 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 [8] indicates that fly ash from NTPC, Parawada, India, can be mixed up to 60% with Thagarapuvalasa soil for use in embankments and subgrades with satisfactory geotechnical characteristics. Reference [9] presented the geotechnical characteristics of fly ash from NTPC, Parawada, Visakhapatnam when fly ash is used alone without mixing with soil as structural fill material.

III. MATERIALS AND METHODS

The fly ash from HNPC, hereafter referred to as HNFA, is collected from the Ash silo of the plant, packed into two 50 kg bags and transported to the geotechnical engineering laboratory, ANITS. Fig.1 shows the sample of HNFA, which is whitish gray in colour. Table-I shows the chemical composition of HNFA. Which indicates that HNFA is a low-calcium Class F fly ash.

Fig.1 HNFA Sample

The fly ash samples have been subjected to Wet & dry sieve analysis, Hydrometer analysis, LL & PL, Specific gravity, Differential free swell and IS Heavy compaction (Modified Proctor) tests. Direct shear test, CBR Test and Permeability test were also conducted on fly ash samples compacted at OMC. When it was attempted to conduct soaked CBR test on HNFA, the sample did not show any measurable resistance to penetration after soaking. Only unsoaked CBR tests were conducted.

Table- I Chemical Composition of HNFA

S.No.	Chemical Compound	Value
1	SiO_2	68.4
2	$SiO_2+Al_2O_3+Fe2O_3$	81.9
3	CaO	6.3
4	Loss on ignition	1.1

The specific surface of HNFA is determined using Blaine's air permeability apparatus. The Blaine's apparatus is calibrated using the Certified Reference Material (CRM), which is also fly ash. The CRM and its specific gravity and specific surface are obtained from National Council for Cement and Building Materials, Hyderabad. XRD, SEM and FT-IR analysis is carried out at Advanced Analytical Laboratory, Andhra University, Visakhapatnam. X-Ray Diffraction analysis was carried out with Cu-Kα radiation, with a 2θ step size of 0.017° and a 2θ range of 10-90°. The SEM was conducted using JSM 6610LV model SE microscope. The infrared spectroscopy was carried out using IR Prestige21 model FTIR spectrophotometer.

To study the improvement in the properties of HNFA, polyester fibers and lime have been used as admixture in this study. Polyester fibers are engineered micro-fibers, similar to polypropylene, widely used as secondary reinforcement in concrete. Table-II shows the comparative properties of Polyester and Polypropylene. Commercially available HiTech-Gold lime is used in the study and obtained from Vijaya Lime Products. Fig.2 and Fig.3 show the samples of Polyester and lime respectively.

Table-II Properties of Polyester

Item	Description/ Value	
	Polyester	**Polypropylene**
Cut length	6 mm	6 mm
Effective diameter	20μ-40μ	25μ-40μ
Cross section Shape	Triangular	Triangular
Specific gravity	1.34-1.39	0.90-0.91
Young's modulus, MPa	>5000	>4000
% Elongation	20-60	60-90
Brand	Recron 3s	Recron 3s
Manufacturer	Reliance Industries Limited	

The percentage of admixture used in the study is shown in Table -III, which is decided based on the previous studies as well as keeping the cost of the admixture in mind.

The fly ash is the mixed with the required of admixture in dry powder form, mixed thoroughly and the OMC, MDD and CBR are determined. These tests are conducted immediately after adding required water (0 days curing). To study the effect of curing, the dry HNFA and the admixture are added with required water, covered the containers with wet cloths and cured for 2 days. Heavy compaction and CBR tests are conducted after 2 days curing. CBR tests are conducted at their respective OMC.

Fig.2 Polyester Sample used in the study

All the tests have been done as per relevant Indian Standards (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.

Fig.3 Commercial Lime sample used in the study

Table-III Admixtures used in the study (% by weight)

(a) Polyester

Polyester (%)	0	2	4	6
HNFA (%)	100	98	96	94

(b) Lime

Lime (%)	0	5	8	10
HNFA (%)	100	95	92	90

IV. RESULTS AND DISCUSSION

A. Physical and Index Properties of HNFA

The physical and index properties of HNFA are shown in Table-IV. As per I.S. Soil classification system, the HNFA may be classified as Silty Sand (SM). Fig.4 shows the grain size distribution curve of HNFA. It may be noted from Fig.4 that HNFA is poorly graded with more than 85% of the particles in the narrow size range of 0.053 mm to 0.6 mm.

Table-IV Physical and Index properties of HNFA

S.No.	Physical /Index Property	Value
1	Specific Gravity	2.01
2	% Gravel	0
3	% Sand	53.5
4	% Silt	44.5
5	% Clay	2
6	Liquid limit, %	12.5
7	Plastic Limit	NP
8	Differential free swell, %	0

B. Morphological characteristics of HNFA

The specific surface measurements of HNFA are shown in Table-V. Fig.5 shows the XRD pattern of HNFA, showing crystalline phases of Quartz, Mullite, gypsum/anhydrite and lime. Presence of Quartz is indicated by the very strong peak at 2θ of 27° and other peaks at 21.28°, 39.73° and 50.61°, while Mullite is indicated by the strong peaks at 41.296° and 61.037° and other peaks at 16.95°, 33.699° etc. The peak at 31.377° is likely to indicate gypsum/anhydrite and the peaks at 54.469° and 64.855° may indicate lime.

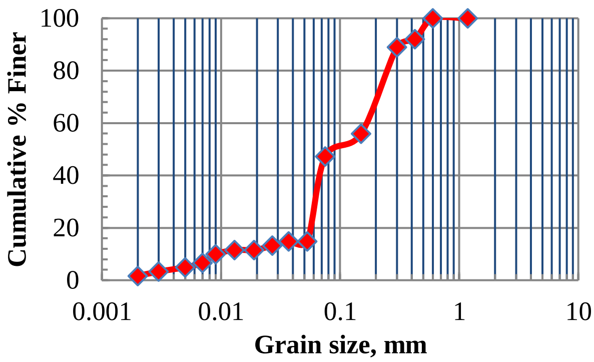

Fig. 4 Grain size distribution curve of HNFA

Table-V Specific Surface Measurements

Material	Specific Gravity	Weight of Sample (g)	Time of Fall of Manometric Liquid in Column (Sec)	Specific Surface Area (cm^2/g)
CRM	2.23	2.11	18.66	3100
HNFA	2.01	1.868	11.66	2721.9

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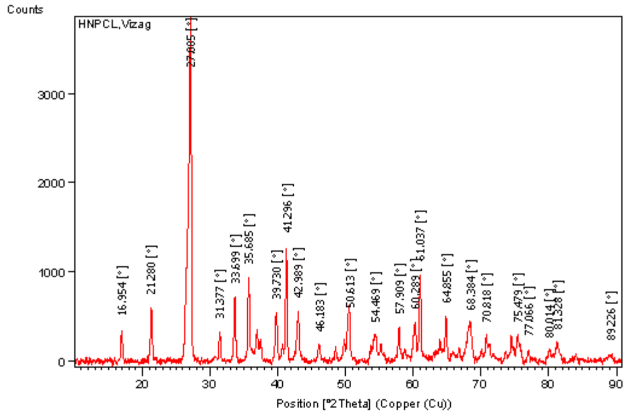


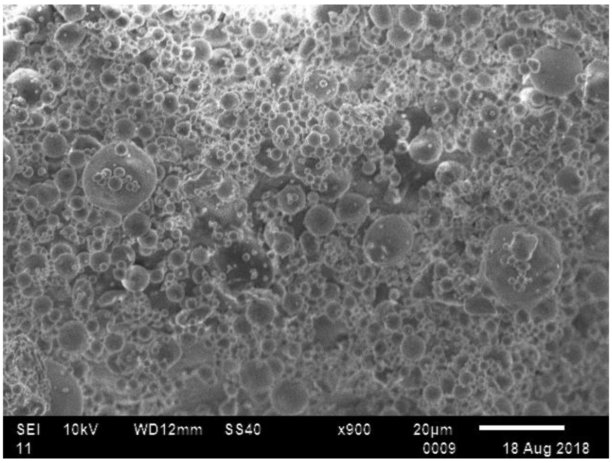
Fig.5 XRD Pattern of HNFA

Fig.6 shows the scanning electron micrographs of HNFA with different resolutions of (a) 20 µm (b) 5 µm and (c) 2 µm. It may be observed from the Fig.6(a) that most of the particles are spherical in shape. While a few particles are of size 15-18 µm, all the remaining are of smaller size. Some non-spherical shaped particles are also seen, but this is due to closely associated small spherical particles adjoining a large particle. A few particles in Fig.6(c) are clay size but their percentage by weight is small compared to the other larger particles.

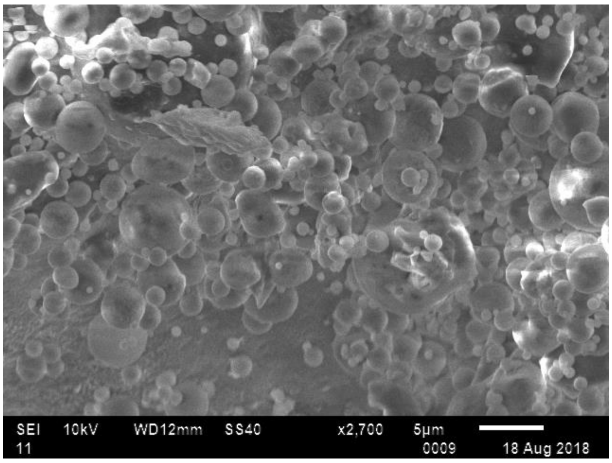
Fig.7 shows the FT-IR spectrum of HNFA. The main absorption band of the valence oscillations of the groups Si-O-Si in quartz appears at 1095 cm^{-1}. The band at 459 cm^{-1} is attributed to Si-O-Si bending. The band at 2360 cm^{-1} may be due to carbon impurities. The FT-IR spectrum of HNFA does not show a broad intense band in the region 3400-3600 cm^{-1}, which confirms the absence of hydroxyl groups on the surface of HNFA.

C. Engineering Characteristics of HNFA

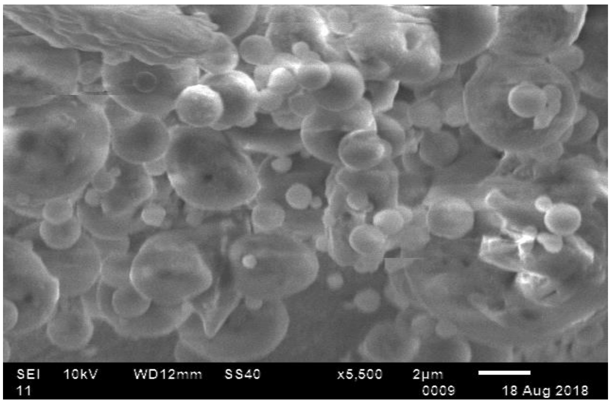
Fig.8 shows the water content-dry density relation for the HNFA under I.S. Heavy compaction. The MDD obtained for HNFA is 13.9 kN/m^3 at OMC of 13.2%. Unlike soils, the dry density of HNFA is not significantly sensitive to water content.



(a) Resolution 20µm



(b) Resolution 5µm



(c) Resolution 2µm

Fig.6 Scanning Electron Micrographs of HNFA

Fig.9 shows the normal stress-shear stress relation for HNFA. The strength envelope appears to be non-linear with decreasing friction angle at increasing in normal stress. At normal stress less than 200 kPa, the strength envelope cuts the X-axis yielding negative cohesion. A best-fit linear strength envelope has been drawn with zero cohesion as shown in Fig.9, which has an R^2 value of 0.96. Thus the shear parameters obtained are c=0 and ϕ=22.5°.

The unsoaked CBR test of the HNFA yielded a load penetration curve that is concave upward at initial values of penetration. Zero correction is therefore applied to the load penetration curve and the unsoaked CBR determined from the corrected curve is found to be 30.3%.

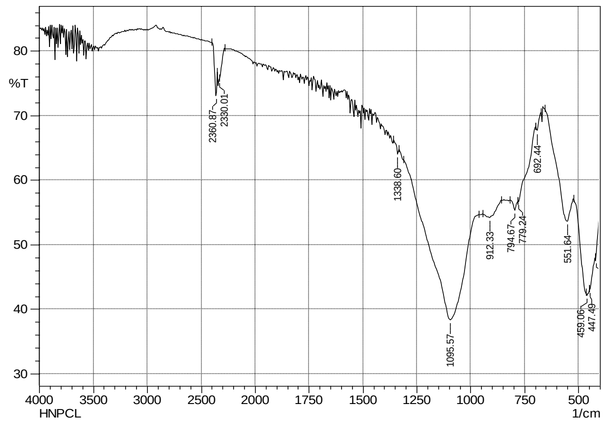


Fig.7 FTIR Spectrum of HNFA

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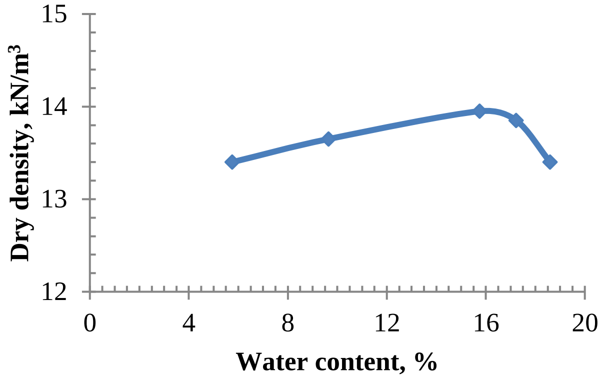

Fig.8 Compaction Curve for HNFA

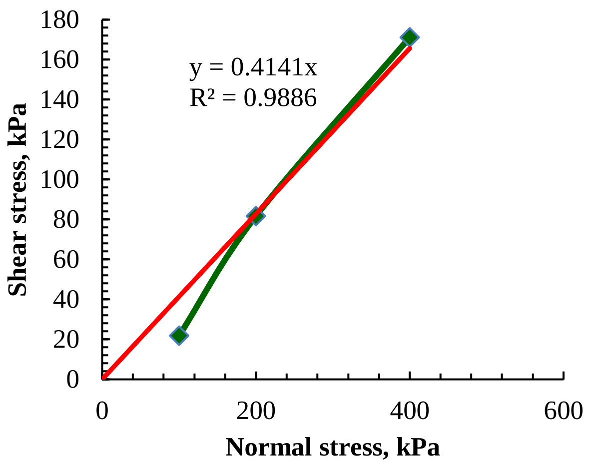

Fig.9 Normal stress–Shear stress relation for HNFA

The permeability of HNFA was determined by falling head test and was found to be 7.9 $\times 10^{-5}$ cm/s, which falls in the range of permeability of dense sand and fine silt. Table-VI summarizes the Engineering properties of HNFA without admixture.

D. Effect of Polyester and Lime on OMC and MDD of HNFA

The HNFA added with the admixture in the given proportions (see Table-III) are tested for OMC&MDD and CBR at 0 days and 2 days curing.

Fig.10 and Fig.11 show the variation of OMC and MDD of HNFA with addition of polyester respectively. OMC of HNFA is observed to increase considerably with increase in % of polyester with and without curing. The MDD of HNFA is found to decrease significantly with increase in % of Polyester and there is almost no effect of curing on MDD. Presumably, polyester absorbs water leading to increase in OMC and also as the specific gravity of polyester (~1.34) is significantly less than that of the HNFA, it leads to decrease in MDD.

Table-VI Engineering Properties of HNFA

S. No.	Characteristic	Unit	Value
1	OMC	%	13.2
2	MDD	kN/m^3	13.9
3	Cohesion	kN/m^2	0
4	Friction angle, ϕ	deg.	22.5
5	CBR	%	30.3
6	Permeability	cm/sec	7.94×10^{-5}

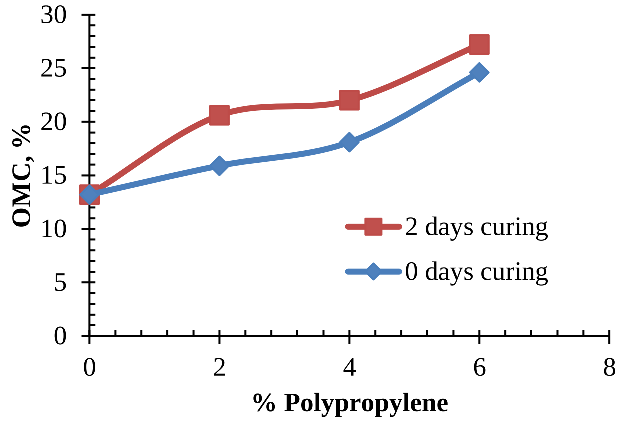

Fig.10 Influence of Polyester on OMC of HNFA

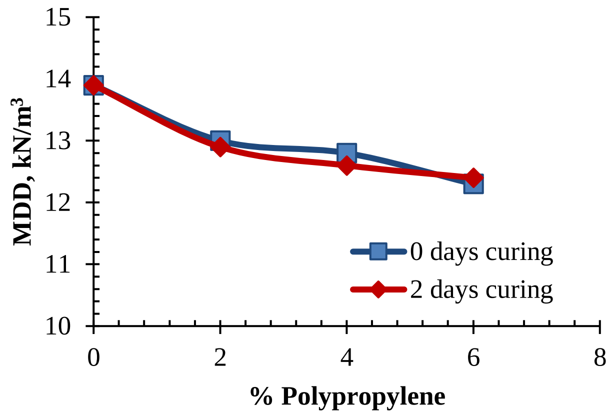

Fig.11 Influence of Polyester on MDD of HNFA

Fig.12 and Fig.13 present the variation of OMC and MDD of HNFA with addition of lime. Increase in % of lime increases the OMC up to lime content of 5% and further increase in lime content decreases the OMC marginally for samples without curing. For cured samples, the decrease in OMC at lime content >5% is more pronounced. MDD of HNFA increases with increase in lime content and the effect is more pronounced for samples cured for 2 days than those without curing.

Reference [10] also reported that the OMC and MDD of Neyvelli and Muddanur fly ashes increase with increase in lime content.

Reference [11] reported that both OMC and MDD of Badarpur fly ash, Delhi increase when the lime content increases from 4 to 8%. Further increase in lime content from 8 to 12% increased the OMC but decreased the MDD.

E. Effect of Polyester and Lime on CBR of HNFA

Fig.14 presents the effect of polyester on CBR of HNFA. It may be observed that CBR increases from 30.3% to 34.7% when the polyester content increases from 0 to 2%. Further increase in polyester decreases the CBR of HNFA marginally. The increase in CBR may be due to the reinforcing effect of polyester in HNFA. Curing does not appear to have any positive influence in enhancement of CBR of HNFA admixed with polyester.

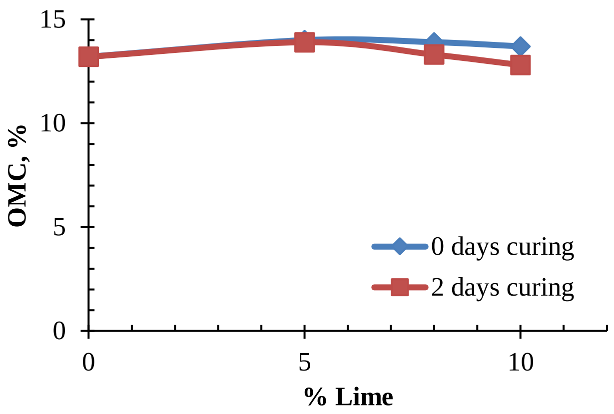

Fig.12 Influence of Lime on OMC of HNFA

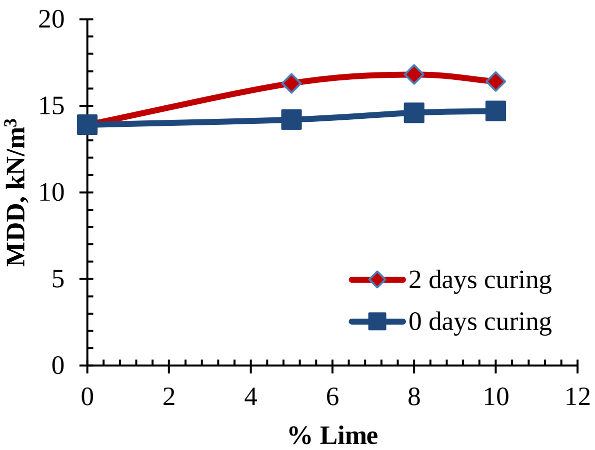

Fig.13 Influence of Lime on MDD of HNFA

Fig.15 presents the effect of lime on CBR of HNFA. CBR of uncured HNFA increases significantly from 30.3% to 41.8% when the lime content increases from 0 to 10%. When curing is done, CBR of HNFA increases considerably from 30.3% to 54.7% when the lime content increases from 0 to 5%. Further increase in lime content from 5 to 10% decreases the CBR of HNFA, but it is still higher than CBR of HNFA without lime. Reference [11] also reported increase in unsoaked CBR with increase in lime content and curing period. Addition of lime to fly ash causes formation of CSH gels due to hydration which leads to increase in CBR value and the amount of gel formation increases with curing period.

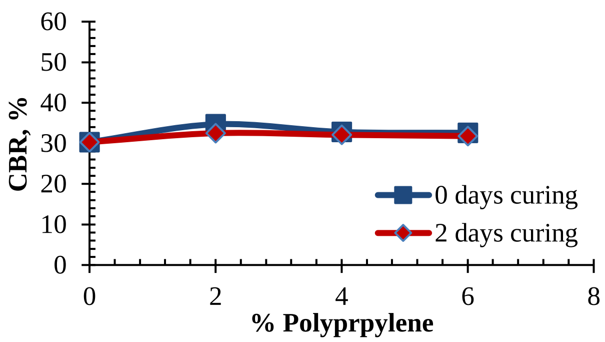

Fig.14 Influence of Polyester on CBR of HNFA

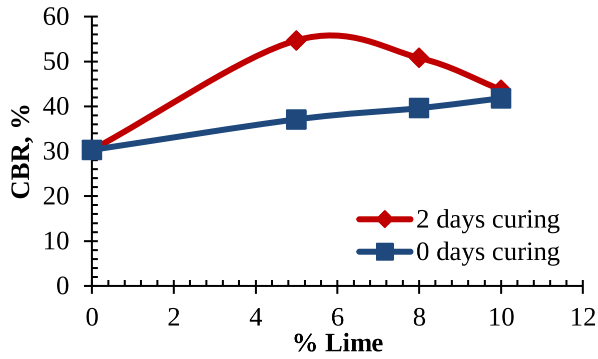

Fig.15 Influence of Lime on CBR of HNFA

V. CONCLUSIONS

Following conclusions may be drawn from the present study:

1) HNFA possesses reasonably good shear strength and unsoaked CBR for use in embankment and subgrade of highways, to promote bulk utilization of fly ash.
2) Polyester did not improve the CBR of HNFA significantly and its use as admixture requires further investigation.
3) Use of lime as admixture to HNFA appears promising to improve the CBR significantly and the optimum lime content is found to be 5% with 2 days curing, for which the CBR of HNFA increased from 30.3% to 54.7%.
4) As HNFA shows poor resistance to penetration under soaked condition, the fly ash embankments with HNFA need to be provided with a soil cover of suitable thickness at the top and sides.

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