DO IT YOURSELF

RURAL ROADS CONSTRUCTION

USING FLY ASH

CONTENTS

1.0 Introduction

Coal is the most easily available fuel for power generation in India, and ever growing demand of electricity will continue to make use of this source of energy. Thermal power stations generally use coal of lower grades with ash content as high as 30 to 50 percent. Higher grades of coal are reserved for metallurgical applications. When pulverised coal is burned in a furnace at the power stations, it produces very fine ash called “Fly ash” which comes out of the furnace along with flue gases. Fly ash accounts for about 75-85 per cent of the total ash formed. The remaining coarser fraction of the ash falls to the bottom of the furnace where it sinters to form “Bottom ash”. Fly ash is removed from the flue gases using electrostatic precipitators (ESP) and is initially collected in ESP hoppers. This ESP dry fly ash is conveyed to the silos pneumatically from where it is generally taken by the user agencies. Bottom ash (after crushing by jaw crusher) and available fly ash from hopper/ silos are mixed with water and disposed off in a slurry form to ponds. This deposit is called “Pond ash”. However, generally the term fly ash is used as a generic name to denote any of these three types of ashes.

Figure-I: Thermal Power Station (Source - Wikipedia)

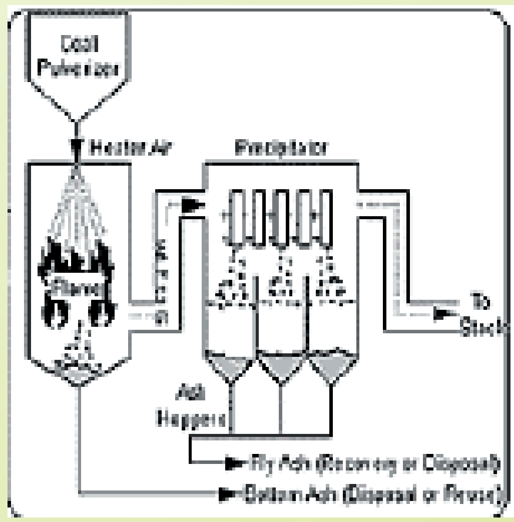

Figure-II: Fly ash Generation in Thermal Power Station

Fly ash availability is widely spread across the country. The details of thermal power stations, their capacities and availability of fly ash is available on website of Central Electricity Authority (www.cea.nic.in). A general map of locations of thermal power plants is placed at Figure-III may be referred in this regard.

1.1 Properties of Fly Ash

The physical and chemical properties of fly ashes vary, with in acceptable range, depending upon the type of coal, its grinding and combustion techniques, and their collection and disposal systems. Fly ash (especially when collected from ESP in dry form) reacts with lime in presence of moisture to form cementitious compounds. This is known as pozzolanic activity. The pozzolanic property of fly ash enables it to be used in concrete to replace a part of cement. When fly ash is disposed in slurry form (mixture of ash and water) to ash ponds, its pozzolanic property gets reduced As a result pond ash (and also bottom ash) are not considered to be suitable for cement replacement, but they can be used as fill material for embankment construction or for mixing with moorum to improve CBR/ plasticity properties of moorum. The indicative range of physical and chemical properties of Indian fly ashes are given in Table I & II:

Figure-III: Thermal Power Plants in India

Table-I: Range of Physical Properties		
Parameters	**Fly Ash**	**Natural Soil**
Bulk Density (gm/cc)	0.9-1.3	1.3-1.8
Specific Gravity	1.6-2.6	2.55-2.75
Plasticity	Lower or non-plastic	Could be much higher
Shrinkage Limit (Vol stability)	Higher	Could be much lower
Grain size	Major fine sand / silt and small per cent of clay size particles	Sand/silt/clay size particles depending upon type of soil
Clay (percent)	Negligible	Could be much higher
Free Swell Index	Very low	Variable
Classification (Texture)	Sandy silt to silty loam	Sandy to clayey silty loam
Water Holding Capacity (WHC) (per cent)	40-60	05-50
Porosity (per cent)	30-65	25-60
Surface Area (m^2 / kg)	500-5000	-
Lime reactivity (MPa)	1-8	-

Table-II: Range of Chemical Composition of fly ash, pond ash and soil			
Compounds (per cent)	**Fly Ash**	**Pond Ash**	**Soil**
SiO2	38-63	37.7-75.1	43-61
Al2 O3	27-44	11.7-53.3	12-39
TiO2	0.4-1.8	0.2-1.4	0.2-2
Fe2 O3	3.3-6.4	3.5-34.6	1-14
MnO	b.d-0.5	b.d-0.6	0.02-0.1
MgO	0.01-0.5	0.1-0.8	0.2-3
CaO	0.2-8	0.2-0.6	1-7
K2 O	0.04-0.9	0.1-0.7	0.4-2
Na2 O	0.07-0.43	0.05-0.31	0.2-3
LOI	0.2-5.0	0.01-20.0	5-16
pH	6-8	6.5-8.5	4.5-8.0
bd : below detection ; LOI : Loss on Ignition			

1.2 Gainful utilisation of fly ash

There has been steady rise in the production of fly ash over the years due to increased demand for power and the dependence on coal for producing electricity. Figure-IV depicts fly ash generation and utilization since 1994 and Figure-V given an overview of fly ash utilization in various sectors. Construction of roads offers a gainful way for bulk utilisation of fly ash. CSIR-Central Road Research Institute itself and also under projects of Fly Ash Mission, Dept. of Science & Technology, Govt. of India has carried out extensive research over many years and developed techniques for using fly ash in various ways in road construction. Many demonstration road projects using fly ash have also been constructed in association with state PWDs.

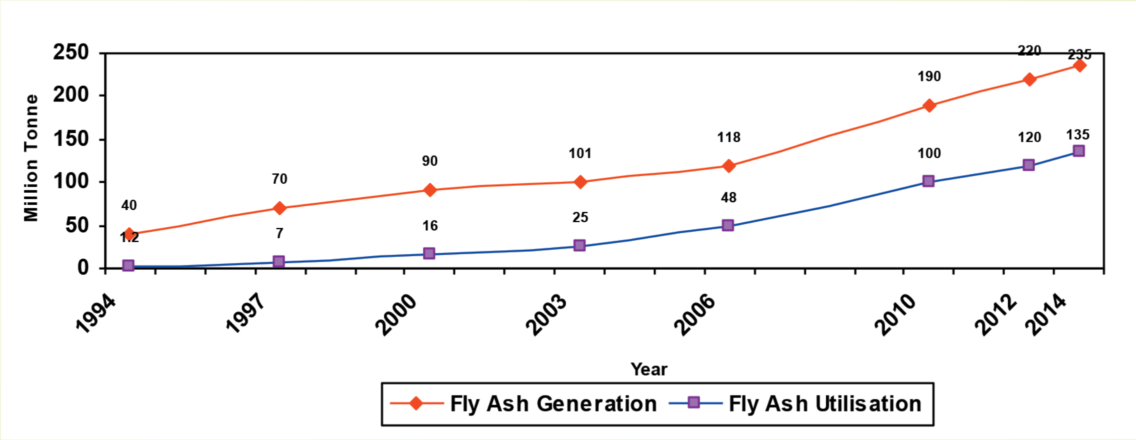

Figure IV: Fly ash generation & utilization

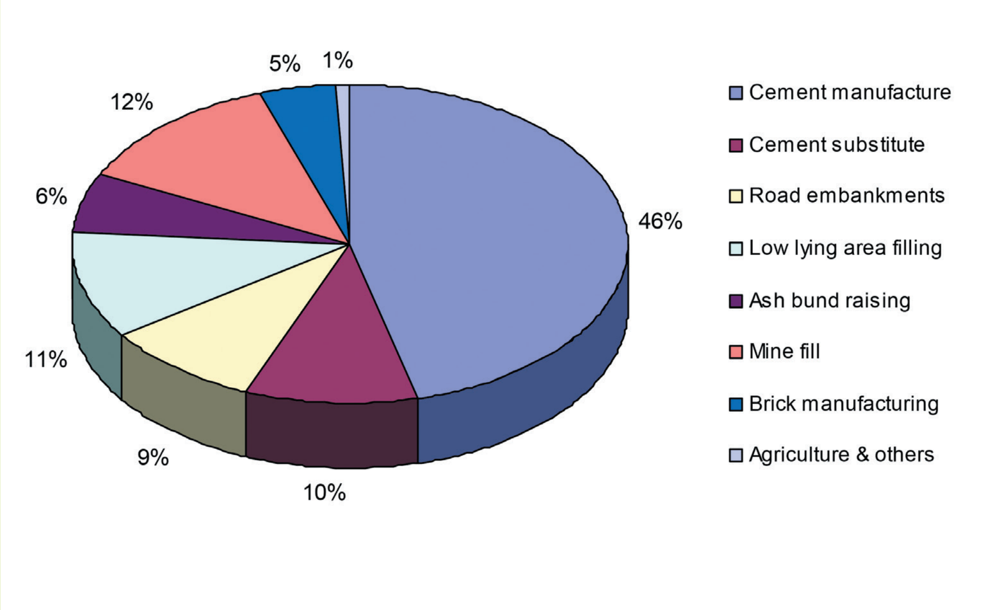

Figure-V: Fly ash utilization area

2.0 Favourable properties of fly ash for road construction

- Lightweight as compared to commonly used fill material (local soils), therefore, fly ash causes lesser settlements. It is especially attractive for embankment construction over weak sub-soils (clayey sub-soils) where excessive weight of embankment may cause failure.
- Usually pond ash and bottom ash have higher value of California Bearing Ratio (CBR) as compared to soil, which can lead to less pavement thickness
- Pozzolanic hardening property imparts additional strength to the road pavements/ embankments
- Amenable to stabilisation using cement or lime
- Can be compacted over a wide range of moisture content, and therefore, results in lesser variations in density with changes in moisture content
- Easy to handle and compact because the material is lightweight and there are no large lumps to be broken, fly ash is available in powdered form
- Can be compacted using either vibratory or static rollers
- Offers greater stability of slopes due to higher angle of friction. Value of angle of internal friction increases even more upon compaction.
- High permeability ensures free and efficient drainage. After rainfall, water gets drained out quickly ensuring better workability than soil, especially during monsoons. Work on fly ash fills/ embankments can be restarted within a few hours after rainfall, while in case of soil it requires much longer time period
- Faster rate of consolidation; a major part of decrease in volume occurs during primary consolidation phase, which is generally rapid, thus making it an ideal material for embankment fills
- Considerably low compressibility results in negligible subsequent settlement within the fill
- Conserves good earth, which is precious topsoil, thereby protecting the environment

3.0 Construction of fly ash embankment

Pond ash is the preferred material for embankment construction. Bottom ash, if available separately in a thermal power station, can also be used for embankment construction. The geotechnical characteristics of fly ash which control its use as an embankment material are compaction characteristics and shear strength. The grain size of fly ash is generally similar to silts. Coarser type of ashes (pond ash and bottom ash) may be having higher amounts of fine sand content. After compacting the original ground/ foundation soil, embankment construction using fly ash can be started. Since fly ash is non plastic powdery type material, vibratory rollers are preferred for achieving better compaction. However, static rollers can also be used successfully for constructing rural road embankments using fly ash, by keeping loose layer thickness to be about 200 mm. Loose layer thickness can be increased to 400 mm if vibratory compactors are used. Rural roads generally have embankment heights less than 2 m or so, hence they can be constructed using side slope of 1:1.5 (Vertical:Horizontal). In case of embankments of higher height, side slope of 1:2 (Vertical:Horizontal) is advocated for embankment construction using fly ash.

Fly ash embankments require provision of side covers using good earth. Fly ash is a non plastic material, without any cohesion and its ‘c’ value would be zero. Because of this nature, it is prone for erosion. Fly ash embankment if left unprotected would erode due to rain and even wind. Hence side slopes should be protected using soil and fly ash should be used to construct core (inside) portion of the embankment. Any soil fill material which is suitable for usage in embankment construction (which satisfies criteria laid down in MORD Specifications for using soil as an embankment fill material) can be used for constructing side cover. Soil available in the roadway can also be utilised (after digging a trench) if feasible (Figure-VII). The soil used for cover should have maximum dry density more than 1.52g/cc when height of embankment is upto 3 m and in areas not subjected to extensive flooding, otherwise the maximum dry density of cover soil should not be less than 1.60 g/cc when tested according to IS:2720 (Part 8)-1983. Subgrade/earthen shoulder material should have minimum compacted dry density of 1.75 g/cc. Plasticity index of cover soil should be between 5 to 9 percent. Chemical analysis or determination of deleterious constituents would be necessary in salt-infested areas or when presence of salts is suspected in the borrow material. Expensive soils should not be used for construction of cover, unless it is properly stabilised using lime. The thickness of side soil cover depends upon height of embankment. For rural roads having embankment height less than one m, about 30 cm thick soil cover would suffice. For embankments of higher heights generally 50 cm thick soil cover is provided. Soil cover and fly ash are to be laid and compacted simultaneously (Figure-VIII). When fly ash embankments are to be constructed for height more than 3m, intermediate soil layers are provided and side cover thickness should also be increased. Turfing on side slopes reduces chances of any rain-cut formation.

For more details regarding construction of Fly Ash Embankment and quality control aspects, IRC Special Publication IRC SP:58 and Clause 306 of MORD Specifications for Rural Roads-2014 can be referred to.

Figure-VI: Pond ash collection for testing from an ash pond in thermal power station

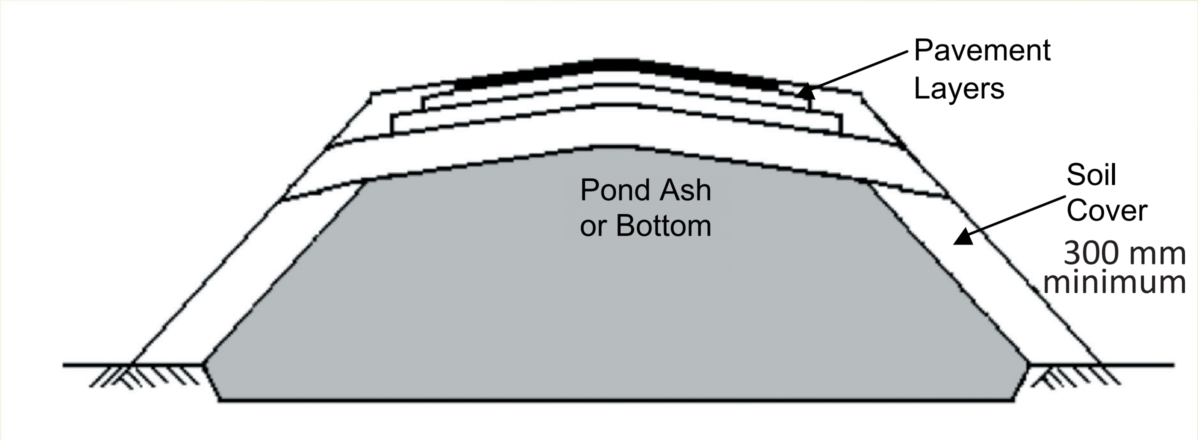

Figure-VII: Typical Cross Section of Fly ash Road Embankment

Figure-VIII: Compacting fly ash and side soil cover for rural road embankment

Figure-IX: Fly ash embankment construction in various road projects

In case, the subgrade soil at site is of CBR about 5% and above, a reverse trench method can be adopted for using fly ash and minimising the quantity of earth from borrow pits. In such cases, after laying out the alignment a trapezoidal cross sectional trench (as shown in Figure X) can be excavated and material stacked on sides. The trench then can be filled in layers with appropriate compaction. Even the core of embankment can be made of fly ash above ground and the excavated earth can be used for making all round cover of 300 mm including subgrade.

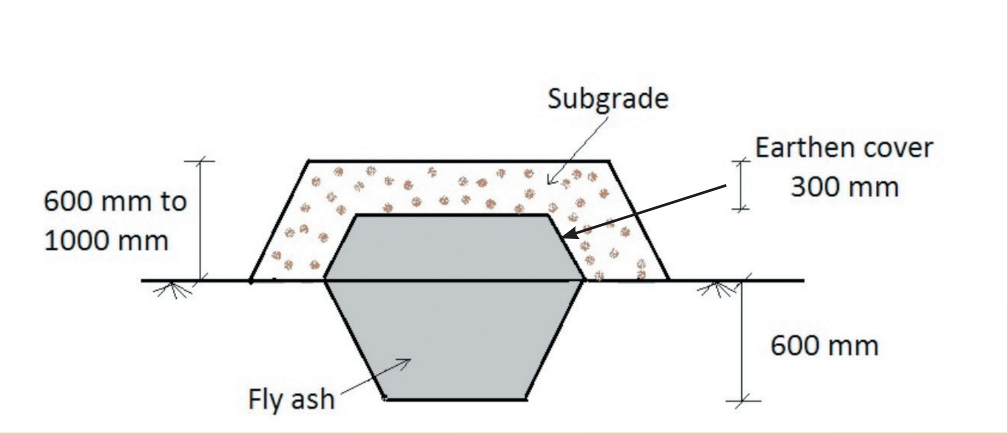

Figure-X: Fly ash embankment construction where CBR is 5% and more

4.0 Highlights of Section 306, MORD Specifications - Fly ash Embankment Construction

- Fly ash embankment to have appropriate side cover made by using soil suitable for embankment construction
- The term fly ash shall cover all types of coal ash such as pond ash, bottom ash or mound ash.
- Particle size analysis of the material as per wet sieve analysis and Standard proctor compaction test results to be submitted for Engineer's approval
- If fly ash is in dry state, it should sprinkled with water and transported in covered trucks
- Fly ash embankment should be compacted to atleast 98 per cent of maximum dry density (Standard Proctor Compaction test)
- Top of the embankment to be covered by 500 mm thick earth cover out of which 300 mm shall be subgrade
- Fly ash embankment shall be measured separately for (a) Soils used for cover and intervening layers (b) Fly ash

Table-III: Typical Geotechnical Properties of Fly ash (Ref: Table 400.18 of MORD Specifications)

Parameter	**Normal Range**
Specific Gravity	1.90 - 2.55
Plasticity	Non Plastic
Maximum Dry Density (gm/cc)	0.90 - 1.60
Optimum Moisture Content (%)	38.0 - 18.0
Cohesion (kN/m^2)	Negligible
Angle of internal friction	300 - 400
Coefficient of Consolidation Cv (cm^2/sec)	$1.7x10^{-5}$ - $2.0x10^{-3}$
Compression Index (Cc)	0.05 - 0.40
Permeability (cm/sec)	$8x10^{-6}$ - $7x10^{-4}$
Particle size distribution (% of materials) Clay size fraction (Less than 0.002 mm) Silt size fraction (0.075 to 0.002 mm) Sand size fraction (4.75 to 0.075 mm) Gravel size fraction (80 to 4.75 mm) Coefficient of Uniformity	1 - 10 8 - 85 7 - 90 0 - 10 3 - 11

Under New Technology initiative guidelines, it has been brought out that all round earth cover of 300 mm will be sufficient, in place of 500 mm as indicated in MoRTH specifications.

5.0 Fly ash usage for constructing road subgrade

Many pond ashes possess very good CBR value. Tests conducted at CSIR-Central Road Research Institute on 15 samples of pond ash showed CBR value varying from 4 to 22 per cent with an average CBR value of 13 per cent. Using pond ash alone for subgrade construction would not be advisable since pond ash being non plastic, it is prone for erosion. Many in-situ soils which have significant clay content, possess high plasticity, low CBR and hence generally considered unsuitable for subgrade construction. By mixing pond ash with such in-situ soils, CBR value can be increased and plasticity of the soil can be reduced. The ratio of mixing pond ash and soil can be decided based on mechanical stabilisation technique (given in IRC SP:89-2010) which depends on grain size distribution of pond ash and soil. As per MORD Specifications, maximum dry density (MDD) of subgrade material should be 16.5 kN/m3 when tested as per IS 2720 (Part 7). This aspect should also be considered while designing the mix. Intimate mixing of these two materials must be ensured for success of this technique. Tractor towed rotavator or disc harrow can be used for mixing soil and pond ash. Table-IV shows test results on pond ash from Panipat thermal power station and local soil. Bottom ash if available can also be used in a similar way.

Table – IV: Tests on Pond ash Local Soil Mixes from Panipat

Mix Proportions (per cent)	OMC (%)	MDD (kN/m^3)	CBR (%)
100 % Pond ash	25.0	14.3	37
35% Insitu Soil + 65% Pond ash	16.8	16.2	25
25% Insitu Soil + 75% Pond ash	19.3	15.4	29
100% Insitu Soil	13.5	18.5	3

For more details regarding construction of Fly Ash Embankment with Subgrade and quality control aspects Clause 306 of MORD Specifications for Rural Roads – 2014 can be referred to.

6.0 Fly ash usage for improving moorum/ gravel to construct GSB layer

Similar to subgrade improvement, pond ash can be used for improving the gradation or plasticity or CBR of moorum. Many locally available moorums have high plasticity properties rendering them unsuitable for using in GSB layer. To improve such moorums, river sand is generally mixed with them. Instead of river sand, pond ash wherever available can be a suitable alternative. The proportion of mixing pond ash and moorum would have to be determined based on mechanical stabilisation technique as given in IRC SP:89-2010.

7.0 Cement or lime stabilised fly ash for sub-base / base course

Fly ash chemically reacts with lime or cement, but much of the reactivity of fly ash is lost when it is mixed with water and disposed to ash ponds. Hence for use in lime or cement stabilisation, fly ash collected in dry form is preferred. Pond ash can also be stabilised using cement. But, cement requirement for pond ash stabilisation may be higher than cement required for fly ash stabilisation. Lime stabilisation is generally carried out using quick lime (CaO) or hydrated lime Ca(OH)2. IRC SP:89-2010 stipulates that purity of lime (CaO content) should be atleast 50 per cent for using commercially available lime for stabilisation. However, it is difficult to ensure good quality of lime (lime with specified CaO content) since lime is mostly manufactured in a small scale by unskilled operators.

For cement stabilisation, ordinary Portland cement, Portland pozzolana cement or Portland slag cement (IS:269, 455 or 1489) can be used. MORD Specifications for Rural Roads provides gradation limits for cement stabilised base course and sub-base course materials. Fly ash or pond ash being fine grained materials may not conform to gradations suggested in MORD Specifications. But this should not be constraint for using fly ash in cement stabilised layer, since fly ash responds to cement stabilisation in a very good manner and develops adequate unconfined compressive strength. As per MORD Specifications, cement stabilised mix shall be designed for a minimum laboratory 7 day compressive strength of 2.76 MPa for use in base course and 1.70 MPa for sub-base. In case cement stabilised fly ash (cement+fly ash mixture) does not develop adequate compressive strength to be used for base course construction, addition of coarse aggregates to cement+fly ash mixture can lead to considerable improvement in compressive strength. Cement stabilised material should also be tested for durability as specified in IRC SP:89. Table-V shows comparison of gradation of fly ash and pond ash from Kahalgaon thermal power station with that of gradation of cement stabilised material as specified in MORD Specifications. Table-VI shows unconfined compressive strength test results for cement stabilised fly ash and pond ash from Kahalgaon thermal power station. Table-VII and VIII show chemical and physical requirements of fly ash to be used as a pozzolana, as given in MORD Specifications.

Table –V: Comparing gradation of Kahalgaon Thermal Power Station Ash for Cement Stabilisation

IS Sieve	Per cent by weight passing (Range as per Table 400.5 of MORD Specifications)		
	Cement Stabilised Sub-base / base	**Fly ash Gradation**	**Pond ash Gradation**
53 mm	100	100	100
37.5 mm	95 – 100	100	100
19 mm	45 – 100	100	100
9.5 mm	35-100	100	100
4.75 mm	25-100	100	100
600 micron	8 – 65	100	100
300 micron	5 – 40	99	98
75 micron	0 – 10	93	74

Table-VI: Unconfined Compressive Strength (UCS) Cement stabilised Kahalgaon Power Station Ashes

Test		Pond ash	Fly ash
UCS of Un-stabilised ash		0.04	0.05
UCS after 3 days curing (MPa)	3% Cement	0.25	0.46
	6% Cement	0.63	0.84
	9% Cement	1.03	1.56
UCS after 7 days curing (MPa)	3% Cement	0.45	0.71
	6% Cement	0.83	1.54
	9% Cement	1.40	1.98
UCS after 14 days curing (MPa)	3% Cement	0.59	0.80
	6% Cement	1.07	2.47
	9% Cement	2.01	4.00

Table-VII: Chemical Requirements for Fly ash as a Pozzolana

Characteristics	Requirements for Fly ash		
	Anthracitic fly ash	Lignitic fly ash	Test Method
$SiO_2+Al_2O_3+Fe_2O_3$ in per cent by mass, Min	70	50	IS:1727
SiO_2 in per cent by mass, Min	35	25	IS:1727
MgO in per cent by mass, Max	25	5.0	IS:1727
SO_3 in per cent by mass, Max	2.75	3.5	IS:1727
Available alkalies as Na_2O/ K_2O			
in per cent by mass, Max	1.5	1.5	IS: 4032
Total chlorides, in per cent by mass, Max	0.05	0.05	IS:1727
Loss on ignition, in per cent by mass, Max	5.0	5.0	IS:1727

Table-VIII: Physical Requirement for fly ash as a Pozzolona

Characteristics	Requirements
Fineness-specific surface in m^2 /kg by Blaine's permeability test, Min	250
Particles retained on 45 micron IS sieve, max	40
Lime reactivity in N/mm^2, Min	3.5
Soundness by autoclave test expansion of specimen in per cent, Max	0.8
Soundness by Lechatelier method-expansion in mm, Max	10

Figure-XI: Preparing, curing and Compressive Strength Test on Cement Stabilised Fly ash

Construction of cement or lime stabilised fly ash layer can be taken up using tractor towed implements. Fly ash in required quantity should be spread over the stretch. Cement or lime bags should be spotted, i.e., required quantity of cement/lime should be placed over uncompacted fly ash layer at required spacing. Mixing of fly ash and cement / lime can be carried out using tractor towed rotavator. Required quantity of water can be sprinkled over fly ash+cement mix and remixed using rotavator. Construction of cement / lime stabilised fly ash layer should be carried out as per MORD Specifications for Rural Roads. For carrying out cement / lime stabilisation in a small scale, labour based technique may also be adopted subject to approval by Engineer.

Figure-XII: Rural Road Construction Using Fly ash and lime stabilisation

Figure-XIII: Rural Road Construction Using Fly ash and cement stabilisation

Figure-XIV: Compacted Stabilised layer

Figure-XV: Tractor towed rotavator

For more details regarding the construction of Lime Fly Ash Stabilised Soil Sub-Base/base and quality control aspects Clause 404 and 409 of MORD Specifications for Rural Roads – 2014 can be referred to.

8.0 Environmental concerns

The major environmental concerns with respect to the potential impact of fly ash usage in road and embankment construction are erosion of fly ash due to run-off, dust nuisance and possibility of leaching of heavy metals into sub-soil. During the construction of fly ash embankments, dust nuisance (fly ash particles being dispersed into air on account of wind) can be minimised by keeping the ash moist. A protective cover of soil is provided for fly ash embankments to prevent such possibilities. Side soil cover protects fly ash core from running water (surface run-off) also. Erosion protection can be enhanced by grass turfing on the side slopes. Access of rain water from the top of embankment can be minimised by providing top soil cover for embankment, i.e. the subgrade and other pavement layers which restrict ingress of water. Indian coal contains a fairly high amount of ash content, hence, concentration of heavy metals in the ash is low when compared to ash obtained from imported coals, which have lesser ash content. As a result the leachates produced have lower concentration of heavy metals. Further, studies done on fly ash from different sources in India have shown fly ash-water mixture to be basic in nature, which tends to restrict the heavy metal leaching. Tests conducted on fly ash and borrow soil have shown that there is practically not much difference in heavy metal concentration that is encountered in soil vis-à-vis fly ash (refer table-IX). Hence, it can be stated using fly ash for road works is safe from environmental point of view. In USA also, Environment Protection Agency (EPA) has classified fly ash as a Non-hazardous waste for its use in road works.

Table-IX: Impact of fly ash on water quality

Parameters	Farmers well; Chargao, Chandrapur	Ash effluent, Chandrapur TPS	Farmers well near ash bund, Chandrapur	Ash pond outlet lagoon, Chandrapur	Vellaha ash pond well no.3, Bhusawal	Vellaha ash pond well no.4 Bhusawal	Farmers well water, Bhusawal	Farmers well water, Bhusawal	Industrial Effluent Standards IS:2490	Drinking Water Standards IS: 10500
pH	8.28	8.14	8.19	8.11	8.23 8.23	8.30	8.10	8.35	5.5-9.0	6.5-8.5
TSS (mg/1)	218.00	362.00	219.10	348.40	349.00	360.00	140.00	75.00	100.00	-
TDS ”	610.00	467.30	587.90	451.70	531.00	535.00	519.00	458.00	-	500.00
Ca ”	65.40	54.20	62.80	51.50	33.50	32.50	37.60	32.50	75.00	75.00
Mg ”	31.00	18.90	29.70	15.30	31.20	29.20	32.80	28.60	30.00	30.00
$N\text{-}NO_3$ ”	3.43	2.21	3.39	2.12	3.70	3.69	2.20	2.39	45.00	45.00
F ”	0.89	1.45	0.97	1.52	0.82	0.81	1.09	1.21	2.00	0.6-1.2
I ”	0.029	0.032	0.026	0.043	0.017	0.020	0.048	0.029	-	-
Fe ”	0.15	0.09	0.11	0.07	0.08	0.08	0.03	0.02	1.00	0.30
Pb ”	0.02	0.05	0.01	0.03	0.05	0.04	0.05	0.05	0.10	0.10
Cd ”	0.003	0.001	0.004	0.001	0.004	0.004	0.002	0.002	2.00	0.10
Ni ”	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	3.00	-
Cr ”	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.10	0.05
Co ”	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	-	-
As ”	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.20	0.05
Hg ”	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	0.001
Radioactivity (Bq/kg)										
α- emitters	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-
β- emitters	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	-	-

9.0 Way forward

Fly ash that was considered as a waste product is a very good construction material for roads and embankments. The engineering benefits obtained due to use of fly ash as embankment fill material and for road pavement construction are well established. Adoption of fly ash for embankment construction will result in saving of precious topsoil besides leading to reduction in construction cost in most of the cases. In addition, there is scarcity of soil and large scale road network may not be possible without use of fly ash as an embankment material. Many road and embankment projects have been completed across the country using fly ash but still numerous practicing engineers are not well versed with fly ash usage. Unfamiliarity regarding use of fly ash in road works can be overcome through demonstration projects and training the engineers/construction agencies. But adequate attention should be paid to characterisation of fly ash and quality control during construction to ensure better performance, so that fly ash can be turned from a liability into an asset.

National Rural Roads Development Agency

Ministry of Rural Development Government of India

5th Floor, 15 NBCC Tower, Bhikaji Cama Place, New Delhi - 110066

Phone: 91-11-26716930/33 Fax: 91-11-26179555 email: nrrda@nic.in

Website: www.pmgsyonline.nic.in, www.pmgsy.nic.in

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