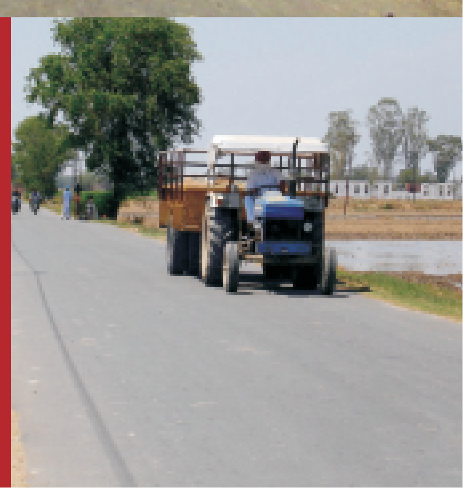
Workshop on Non-Conventional Materials/ Technologies

18th February, 2012
Central Road Research Institute, New Delhi

TECHNICAL PAPERS

National Rural Roads Development Agency
Ministry of Rural Development, Government of India

MINISTRY OF RURAL DEVELOPMENT
Government of India



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PREFACE

Pradhan Mantri Gram Sadak Yojana (PMGSY) is one of the largest infrastructure development initiatives in the country for development of Rural Roads, with technical and managerial support from National Rural Roads Development Agency (NRRDA). Rural Infrastructure is the key to inclusive growth by connecting the rural hinterlands and enabling the roll out of many additional socio-economic sciences

With growing rural road network of the country and with ambitious rural road development plans, the role of R&D inputs becomes most valuable. The main thrust of research and development (R&D) in the roads sector is to build a sustainable and environment- friendly road infrastructure for low volume rural roads.

As technologies are changing at a fast pace, we must be open to new ideas, learn from our experiences and develop the capacity to compete and innovate user friendly technologies. The R&D pilot projects should be targeted to economic and efficient use of new technologies, use of marginal materials and use of waste materials.

The workshop on Non –Conventional Materials/ Technologies is an initiative of NRRDA, under the auspices of the Ministry of Rural Development, Government of India, where Technical Experts, Scientists, Academia, Executing Agencies, Research and Developing Organizations would be assembling on a common platform to discuss various issues related to technical aspects of utilization of Non-Conventional Materials/ Technologies in development of Rural Roads. I hope that the deliberations will lead to building of systems and processes which would facilitate NRRDA and other stakeholders to accomplish the task in a more professional way.

This compendium of technical papers is the result of tireless effort of several eminent experts and our gratitude is due to them. We are confident that the similar support will continue coming to NRRDA in the implementation of PMGSY.

I take this opportunity to acknowledge the help and contribution of all those who made it possible to compile this compendium.

(S. Vijay Kumar)
Secretary, Rural Development

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OVERVIEW OF FLY ASH FOR USE IN RURAL DEVELOPMENT[@]

Vimal Kumar*

ABSTRACT

Fly ash a finally divided mineral residue of burning of coal exhibits excellent geotechnical as well as pozzolanic properties that make it very suitable for all construction activities including roads, embankments and reclamation of low lying areas. Fly ash based construction materials including cement, concrete, bicks, blocks, tiles, pavers, kerb stones, pre-fabricated door frames, window frames, beams, slabs are becoming favourite of construction industry, being durable, economical, eco-friendly, easy to use & of consistent quality.

Fly ash also holds potential to improve the socio-economic status of rural areas by generation of employment & business through manufacture of fly ash based products, their usages in rural development schemes, development of fly ash supply chain, improvement of agriculture yield and land resource management, etc. with fly ash.

The paper, by virtue of the subject of the workshop, has more emphasis on road development usage of fly ash.

Key words: Coal ash, fly ash, rural, development, socio-economic impact, wealth generation, sustainability, green development.

1.0 FLY ASH: A MATERIAL

Fly ash is an excellent material with multifarious properties that make it suitable for wide range of applications. The physical, chemical & geotechnical properties of fly ash are given in Table nos. 1, 2 & 3 respectively. XRD pattern is at Plate no. 1 and micrograph by scanning electron microscope is given in Plate no. 2.

1.1 Fly ash: a ceramic material

The mineralogy of fly ash, by virtue of different matrices of glass, mullite & quartz etc. make it suitable for use as a ceramic material. Ceramic tiles, potteries & wares as well as refractory bricks have been developed by use of fly ash at CGCRI-Kolkata, CGCRI-Khurja, NML-Jamshedpur and CPRI- Bangalore.

This provides ample scope for business & employment generation in rural sector, in addition to large automated manufacturing units elsewhere.

@ Invited paper for "Workshop on Non-Conventional materials/Technologies" organized by NRRDA, Min. of Rural Development, GoI on 18th February, 2012 at CRRI, New Delhi

The views expressed are of the author and not necessarily of the organization of his affiliation.

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1.2 Fly ash: a pozzolanic material

The pozzolanic property of fly ash as represented by its lime reactivity, high surface area (fine ness) & low un-burnt carbon makes it suitable for manufacture of fly ash-sand-lime-gypsum or fly ash- sand-cement bricks, blocks, tiles and other building materials.

Fly ash when added to common soils with or without small percentage of lime, improves the strength of mud blocks. Hand/foot operated as well as low power input machines are available for manufacture of fly ash bricks/ fly ash-mud blocks in rural areas with low investments. Small scale set ups with investments of around Rs. 20 lakhs in plant & machinery are also available for production of fly ash bricks that can be easily consumed in rural development projects.

1.3 Fly ash: a granulometry compatable material

The granulometric & engineering properties of fly ash coupled with flux bonding property of fly ash at low temperatures (around 800^0 C) as compared to sintering temperatures (about1000-1200^0 C) makes fly ash an excellent material to improve the quality & economics of clay bricks. It also helps to conserve the top soil up to 50%. Use of coarse fly ash with clayey soils & fine fly ashes with sandy soils optimizes the granulometry of the material mix & makes it more suitable for manufacture of clay bricks. (Can be termed as clay-fly ash bricks)

Clayey soils, devoid of sand/gravel fractions result in poor quality clay bricks. The presences of high proportion of colloidal particles clog the pores of brick body and affect uniform drying leading to formation of micro-cracks. On the other hand, the bricks made of sandy soils are porous & attain low strength on firing. Fly ash provides the solution for both cases. It replaces use of sand, rice husk or other bought out materials. As a result of improved quality of brick, the losses due to breakage of green as well as fired bricks reduce considerably. Generally it comes down from 3-5% to 1.5-2.5%. High strength bricks also fetch higher price in the market.

1.4 Fly ash: a soil ameliorant & source of micro-nutrients

Fly ash contains major-nutrients such as Ca, Mg and S, secondary-nutrients like Zn, Fe, Cu and Mn in addition to small quantities of P and K. Table-4 provides analysis of fly ash for these elements. The size fractions of fly ash are in between of clayey soils and sandy soils. Thus, addition of fly ash to both types of soils improves aeration, water percolation/ holding capacity, reduces crust formation, improves germination, water & fertilizer use efficiency, etc. As a net result of all these effects, fly ash enhances the yield by about 10-15% for cereals, cash crops, fruits and 25% for vegetables without any adverse effect on soil health, water & quality of produce. The effect of fly ash on yields of various crops is given in Table-5. The impact of radioactivity & heavy metal content of fly ash on soil, water and produce are with in safe and permissible limits, as can be seen at Table nos. 6 & 7.

Fly ash has also been successfully used for reclamation of waste & degraded lands.

Thus fly ash holds immense potential to improve the socio-economic status of rural India by reclaiming waste/ degraded lands & increasing agriculture yield by 10-20%.

1.5 Fly ash: a material for road, embankment & allied structures

Geotechnical properties of fly ash (Table-3), specially high angle of internal friction, low bulk density, wide range of OMC (also see Plate-3), ease of compaction and practically full compaction in the initial stages (no subsequent settlements) etc. make it a preferred choice for the builders.

The pozzolanic property makes it suitable for use in concrete pavements as a part substitution of cement up to 35% in conventional concretes & up to 66% in roller compacted concretes.

It is also a proven material for construction of sub-base layers as well as all season motorable rural roads by stabilization of fly ash by about 2-4% lime.

Standards & guidelines issued by BIS, IRC and Ministry of Rural Development exist for these utilizations.

2.0 CASE STUDIES

2.1 Fly ash products use for rural construction

Shri Nilaya Mitash, I.A.S.,
Managing Director
Rajiv Gandhi Rural Housing
Corporation Ltd.,
Cauvery Bhavan
Bangalore.

15 March 2007

Fly ash produced during the burning of powdered coal in thermal power plants is a hazardous waste. However, its physical and chemical properties make it an ideal raw material for producing high quality and cost-effective bricks, interlocking pavers, kerbstones and mosaic tiles.

Rajiv Gandhi Rural Housing Corporation Ltd. has done pioneering work in using fly ash products in the projects implemented by it. Fly ash-based building components like blocks, bricks, door and window frames are extensively used in the construction of houses in Raichur, Bellary, Uttara Kannada and Shimoga Districts. Raichur Nirmiti Kendra received an award from HUDCO for use of industrial waste as building material.

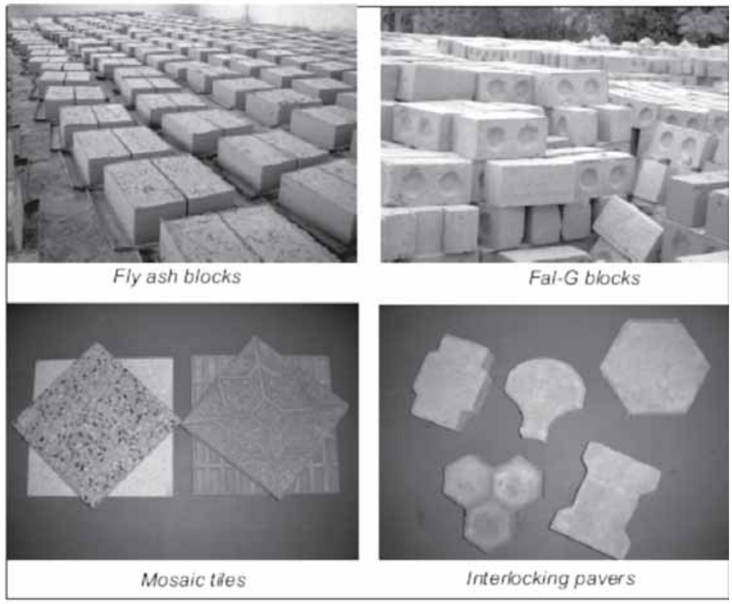
The effort of ENVIS Centre, Karnataka, to popularize the use of fly ash products is laudable.

(Nilaya Mitash)

Techno economic analysis and comparative study of fly ash products manufactured at CASHUTEC

Fly ash Product	Characteristics	CASHUTEC	Convential
Brick (9 x 4.25 x 3) inches	Finish	Excellent	Satisfactory
	Compressive strength	65 - 100 kg/cm2	50 kg/cm2
	Water absorption	10 - 12%	15 - 20%
Block (16 x 8 x 8) inches	Finish	Excellent	Satisfactory
	Compressive strength	50 kg/cm2	35 kg/cm2
	Water absorption	10 - 12%	13 - 15%
Interlocking paver	Finish	Excellent	Good
	Compressive strength	170 - 280 kg/cm2	150 - 200 kg/cm2
	Water absorption	10 - 12%	0.15
Kerbstone	Finish	Excellent	Good
	Compressive strength	215 kg/cm2	150 kg/cm2
	Water absorption	8 - 10%	
Mosaic tile	Finish	Excellent	Good
	Transverse Strength	15 kg/cm2	30 kg/cm2
	Water absorption	3 - 4%	0.1
	Abrasion resistance	1.75 mm	3.5 mm

Fly ash products manufactured at CASHUTEC, Raichur



Evaluation results of fly ash mosaic tiles		
Properties	Fly ash mosaic tiles	IS 1237/CPWD specs
Wet transverse strength (N/sq. mm)	4.5	Not less than 3.0 N/sq. mm when full size tiles are tested
Water obsorption(%)	3.3	Not to exceed 10% when full size tiles are tested
Abrasion resistance (mm)	1.75	Not to exceed 3.5 mm for general purpose. Not to exceed 2.0 mm for heavy duty tiles.

2.2 Fly ash blocks for road pavements

Interlocking paving stones are installed over a compacted stone sub-base and a leveling bed of sand. Concrete paving stones can be used for walkways, patios, pool decks and driveways and airport or loading docks.

Instead of connecting the pavers by pouring grout between the joints as one would with tiles, sand particles are spread over the pavers and tamped down. The sand stabilizes the interlocking pavers, yet allows for some flexibility. This type of pavement will absorb stress such as small earthquakes, freezes and thaws, and slight ground erosion by shifting each tile slightly. Therefore, they will not crack or buckle like concrete, though bad weather may make potholes.

The special tools needed for installing interlocking pavers are vibrating compaction machine or “Vibra Plate” and Shear Cutter. The former is used to compact the base material to 90% density minimum and also to set and interlock the pavers into the sand bed. The latter is used to cut the pieces to fit at corners and edges. The sand does not easily wash out with rain or garden hose water and a sealant can be spread on to further lock the sand.

Standard thicknesses are 60mm (for light traffic) and 80mm (heavy traffic). 50mm too is common in some countries like Pakistan (used for footpaths etc).

Benefits of paver over asphalt and poured concrete include high compressive strengths, pleasant look, time saving, easy removal and relaying.

Concrete paver blocks in a circular pattern

Concrete paver blocks in a rectangular pattern

Brick paving being laid on a sand base, in south west England

Crumbling walkway reveals details of hexagonal pavers (Base preparation& edge protection essential)

2.3 Fly ash concrete road pavements

Bitumen has to be imported in India to build the road pavements. On the other hand, HVFAC roads use locally produced materials, including fly ash, a byproduct, which because of its under utilization, requires large areas of land for its disposal. Therefore, the use of HVFAC roads in India offer significant advantages from the standpoint of economy, performance, and overall environmental benefits.

THE PROJECT

The construction project includes the main road and several shorter sections of road. The total length of the road is approximately 2.3 km, and the total area is about 14,000 m2. The width of the road is 6 m, and its average thickness is 200 mm.

The construction of the road was undertaken during 2004-2005.

THE SELECTION OF MIX DESIGN

MATERIALS USED

The cement used was 53 grade ordinary portland cement.

Texturing of Concrete for anti-skid finish

Chemical Properties	
SiO_2 (%)	60.21
Al_2O_3 (%)	26.08
Fe_2O_3 (%)	4.8
CaO (%)	1.00
MgO (%)	0.30
$K_2O + Na_2O$ (%)	0.86
SO_3 (%)	0.25
Loss on Ignition (%)	1.71
Physical Properties	
Lime reactivity (MPa)	6.10
Fineness (m^2/kg)	330

Chemical and Physical Properties of the Fly Ash from Sikka Power station

- **AGGREGATES**

A mixture of 20-mm and 10-mm maximum size coarse aggregates was used in the concrete.

Proportions of the Concrete Mixtures

	Bottom Layer (50% Fly Ash)
Grade of Concrete	M35
W/CM	0.36
Water, kg/m^3	162
Ordinary Portland Cement (OPC), kg/m^3	225
Fly Ash, kg/m^3	225
Coarse Aggregate, kg/m^3	1374
Fine Aggregate, kg/m^3	456
Water Reducer (Plasticizer), L/m^3	2.7

THE CONSTRUCTION

The mixing was done on site using two portable drum mixers. All the quantities of the ingredients were properly measured, under close supervision, before their introduction in the mixer, to insure good quality control. Once mixed, the concrete was transported through a short distance (a few hundreds of meters) to the casting site with a small truck.

The concrete was consolidated using internal vibrators and leveled by a vibrating screed. Both layers of concrete were vibrated together to make it monolithic. The surface of the concrete was broom-finished to provide an anti-skid texture. The surface was then immediately covered with plastic sheets to protect against evaporation and prevent plastic shrinkage.

The next day, the plastic sheet was removed, and water-curing was done by creating small water ponds on the road surface. The concrete was water-cured in this manner for 28 days.

Transverse contraction joints were provided at 3.5 m intervals by placing 3.5 ms long, 90-mm deep, and 3-mm thick metal strips in the concrete. These metal strips were taken out 2 hours after placing the concrete and were reused.

Expansion joints were provided every 35 meters. Dowel bars, 25-mm diameter, and 0.5 m long were used. Half the length of the dowel bars was greased for free movement and the other half was embedded in concrete.

2.4 Fly ash road embankments

2.4.1 Advantages of fly ash for road construction

- Light weight as compared to conventionally used local construction materials. This will, therefore, cause lesser settlements. It is especially attractive for road construction over weak sub grades such as alluvial clay or Black Cotton soil (BC soil)
- Higher value of CBR (California Bearing Ratio) as compared to silty or clayey soil leads to a more efficient design of road pavement.
- Amenable to stabilization with lime or cement depending on its pozzolanic property.
- Pozzolanic hardening property imparts additional strength to the road pavements.
- Can be compacted over a wide range of moisture content. This will result into less variation in density with changes in moisture content.
- Easy to handle and compact because it is light-weight material and there is no large lumps to be broken down.
- Can be compacted using either vibratory or static roller.
- High permeability ensures free and efficient drainage. After rainfall, water gets drained out freely ensuring better workability than soil, especially during monsoons.
- Conserves good earth and other conventional construction material, thereby protecting the environment.

2.4.2 Fly ash, a good geo-technical material

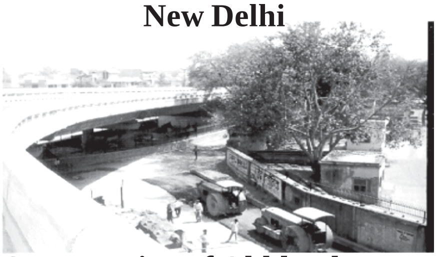
Generally there are some apprehensions because of low dry density of compacted fly ashes. It is felt that because of these properties of fly ash it may not be able to sustain loads and thus may have collapse failure which is not true. The collapse failure is related to the voids in the compacted geo-technical material. If compaction is near to complete, the materials of low compacted dry density would not collapse. In this regard the important parameter is percentage Procter compaction. The low density of fly ash on the other side is an added advantage. By virtue of this property, the fly ash is best suited for construction of embankments on weaker strata's/sub soil. Construction of Okhla Fly Over embankment, near CRRI, New Delhi in mid 1990s and road embankment in widening of National Highway-6 from Dhankuni to Kharagpur had the problems of weaker sub-soil and use of fly ash has provided the solution.

Initially the practicing engineers had some apprehensions about technical feasibility of use of fly ash for road and fly over embankments. The first utilization started in mid 1990s with use of fly ash in half width of embankment of Okhla Fly Over and the construction of balance half width was taken up with soil. The construction work was completed using the reinforced earth technique.

Approach Road Embankment, Nizamuddin

Construction of Sarita Vihar Fly over , New Delhi

Construction of Panjabi Bagh Fly over , New Delhi



Construction of Okhla Fly over, New Delhi

2.5 Fly ash stabilized all weather rural roads

Fly ash stabilized with 3-4% lime without any surface coating for construction of all weather roads at Raichur was constructed around 1997 and monitored for three years by CRRI. No signs of stress were observed.

Rural Road at Raichur

2.6 Standards, Guidelines & Manuals

IRC GUIDELINES RELEVANT TO USE OF FLY ASH IN ROADS & EMBANKMENTS

IRC: SP 62:2004	Guidelines for Design and Construction of Cement Concrete Pavement for Rural Road	Provides for use of fly ash / fly ash based cements in concretes to be used for construction of concrete roads.
IRC:SP:20-2002	Rural Road Manual	The code includes a complete chapter on use of waste materials on construction of rural roads, the major part of which is covered by fly ash. It provides for use of fly ash in various layers of rural roads viz. sub base, base course, wearing course etc.
IRC:SP:58-2001	Guidelines for Use of Fly Ash in Road Embankments	This code provides detailed guidelines for use of fly ash in road embankments. It also gives details about construction of fly ash embankments of heights less than 3 m as well as more than 3 m. This covers all the aspects of construction viz. site survey, investigations, surface preparation, ash filling, compaction, side and top cover of soil etc.
IRC 88 - 1984	Lime-Fly Ash Stabilised Soil Base or Sub-base for Pavement Construction	It provides for use of fly ash in lime-fly ash stabilised soil base or sub-base for pavement construction.
IRC 74 - 1979	Lean Cement Concrete / Lean Cement Fly Ash Concrete as Pavement Base or Sub-base	It provides for use of fly ash in lean cement concrete / lean cement fly ash concrete as pavement base or sub-base
IRC: 68 - 1976	Tentative Guidelines on Cement Fly Ash Concrete for Rigid Pavement Construction	It provides for use of fly ash / fly ash based cements in concrete for construction of rigid pavement.
IRC 60-1976	Use of Lime Fly Ash Concrete as Pavement Base or Sub-base	It provides for use of fly ash and lime for construction of rigid pavement.

3.0 CONCLUSION

Fly ash & fly ash based products have been established for economic, durable & eco-friendly construction & development in rural sector. These products & technologies need to be implemented on large scale in each project/activity of rural development to usher an era of eco-friendly & sustainable rural development vis-à-vis generation of employment and business opportunities.

Table 1. Range of Physical Properties of fly ash Vs soil

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 (per cen)	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 2. Range of Chemical Composition of fly ash, pond ash and soil

Compounds (per cent)	Fly Ash	Pond	Ash Soil
SiO_2	38-63	37.7-75.1	43-61
Al_2O_3	27-44	11.7-53.3	12-39
TiO_2	0.4-1.8	0.2-1.4	0.2-2
Fe_2O_3	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
K_2O	0.04-0.9	0.1-0.7	0.4-2
Na_2O	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

Table 3. Range of Geo-technical properties of fly ash & soil

Parameter Range	Fly ash	Soil
Specific Gravity	1.6-2.6	2.55-2.75
Plasticity (per cent)	Lower or Non-Plastic	could be higher
Maximum Dry Density (gm/cc)	0.9-1.3	1.3-1.8
Optimum Moisture Content (per cent)	18.0-38.0	12-18
Cohesion (kN/m^2)	Negligible	20-150
Angle of Internal Friction(degrees)	30-40	25-35
Coeff. Of consolidation Cv(cm^2/Sec)	1.75X10^{-5}-2.01X10^{-3}	9X10^{-5}-1.1X10^{-3}
Compression index C_c	0.05-0.4	0.1-0.4
Permeability (cm/sec)	8X10^{-6}-7X10^{-4}	3X10^{-8} - 4X 10^{-4}
Particle size Distribution (per cent of materials)		
Clay size fraction	1-10	5-40
Silt size fraction	8-85	20-40
Sand size fraction	7-90	40-80
Gravel size fraction	0-10	0-30
Coefficient of Uniformity	3.1-10.7	1-20

Table 4. Physico-chemical characteristics of soil and fly ash, pond ash and bottom ash

Parameters	Soil		Fly Ash		Pond Ash		Bottom Ash	
pH	8.50		10.00		8.10		8.62	
EC dS/m	0.09		0.62		0.11		0.06	
BD (g/cc)	1.41		0.96		1.08		1.12	
Porosity (%)	48.65		63.00		52.32		52.17	
WHC (%)	23.68		65.33		47.29		46.17	
Particle size								
Sand (%)	80.30		60.50		70.80		86.10	
Silt (%)	14.00		30.30		21.50		11.00	
Clay (%)	5.70		9.20		7.70		2.90	
Major and Secondary Nutrients								
	Total (%)	**Available (ppm)**	**Total (%)**	**Available (ppm)**	**Total (%)**	**Available (ppm)**	**Total (%)**	**Available (ppm)**
Org. Carbon	**0.37**		**0.14**		**0.10**		**0.07**	
N	0.035	0.009	BDL	BDL	0.006	0.001	BDL	BDL
P	0.018	10.40	0.24	17.08	0.20	16.26	0.15	15.43
K	0.63	75.60	0.95	81.00	0.84	69.00	0.82	66.00
S	0.021	13.40	0.089	99.80	0.075	49.20	0.032	25.60
Ca	0.97	19.30	3.86	39.50	3.64	28.60	3.12	27.80
Mg	0.51	15.70	0.68	17.60	0.64	16.90	0.59	15.20

Trace/Heavy Metals (ppm)								
	Total	Available	Total	Available	Total	Available	Total	Available
Cu	32.42	2.06	67.33	0.62	62.59	0.30	63.10	0.34
Zn	46.94	0.97	67.86	0.36	60.25	0.41	60.47	0.47
Mn	305.26	3.49	380.39	0.71	367.84	0.66	356.32	0.59
Fe*	4.20	15.37	3.32	10.21	3.11	10.13	3.14	9.98
Cr	20.31	ND	69.77	0.56	60.14	0.49	60.39	0.51
Co	37.73	ND	53.12	0.14	54.33	0.10	52.51	0.12
Pb	8.66	0.16	30.76	ND	25.49	ND	23.61	ND
Cd	5.11	0.02	10.96	0.04	9.14	0.03	8.20	0.03
Ni	50.24	0.32	65.37	0.19	62.55	0.14	60.72	0.13
Hg	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
As	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Radioactivity (Bq/Kg)								
^{40}K	269.9		277.1		262.8		268.3	
^{226}Ra	30.6		76.4		68.5		71.2	
^{228}Ac	52.7		88.1		74.7		76.3	

*** Total content of Fe is in %**

Table 5. Per cent yield increase in fly ash amended soils over control (without fly ash) for various crops

Sl. no.	Crop	No. of sites	Range	Mode range ave rage (représentative ave rage)*
Cereals				
1.	Wheat	36	2.85-99.20	17.25
2.	Paddy	34	2.90-41.71	13.50
3.	Maize	16	4.00-88.41	21.95
4.	Jowar	07	5.60-32.42	13.47
5.	Bajra	03	7.10-25.00	13.00
6.	Sorghum	03	7.70-28.15	17.00
7.	Oat	01	22.20	22.20
8.	Pearl millet	01	32.30	32.30
Pulses				
1.	Chickpea	04	9.70-30.62	21.00
2.	Green gram	04	5.70-28.20	21.00
3.	Black gram	03	6.20-13.85	11.00
4.	Arhar	01	25.00	25.00
5.	Lentil	01	5.50	5.50
Oil seeds				
1.	Ground nut	17	7.10-77.40	22.23
2.	Sunflower	09	2.60-67.00	28.43
3.	Soybean	08	8.70-63.60	27.22
4.	Mustard	05	5.80-61.80	15.27
5.	Sesamum	02	2.50-7.70	5.10

6.	Raya	01	3.30	3.30
7.	Til	01	40.00	40.00
8.	Linseed	01	21.40	21.40
Cash crops				
1.	Cotton	11	9.30-38.20	18.60
2.	Sugarcane	06	8.70-63.60	27.22
3.	Jute	03	5.00-20.00	19.00
Horticulture crops				
1.	Brinjal	06	0-137.80	12.5
2.	Tomato	04	4.50-29.00	16.50
3.	Potato	04	9.20-37.00	24.50
4.	Onion	02	18.40-26.60	22.50
5.	Banana	01	14.00	14.00
6.	Beetroot	01	14.00	14.00
7.	Bhendi	01	16.70	16.70
8.	Bottle gourd	01	15.80	15.80
9.	Chilli	01	6.70	6.70
10.	Palak	01	11.10	11.10

- **Representative average-**the per cent increase in yields has wide range for the same crop in the same soil and agro-climatic conditions. There can be many reasons for it. To arise at representative average the following procedure has been adopted.
- The percentage increases are listed in the block of 1-10%, 11-20%, 21-30% and so on. Thus 10 blocks would have the percentage increase figures pertaining to representative block. Extreme blocks containing practically same number of entries on the higher side as well as on lower side have been excluded. The central blocks (generally two blocks) having maximum number of entries (representative mode like blocks and also medium type blocks) have been taken and average of all the readings in these blocks are taken as representative average.

Table 6. Impact of radioactivity & heavy metal content of fly ash on soil and produce

Sample	Radioactivity(Bq/kg)			Trace & Heavy metals (ppm)			
	^{40}K	^{226}Ra	^{228}Ac	B	Mo	As	Se
ESP fly ash	280-432.5	43.6-115.4	55-129	17.1-28.0	2.5-6.7	1.0-4.0	1.6-2.6
Pond ash	280-353	69-92	77-108	18.3-23.1	2.6-5.3	1.4-3.6	1.2-2.3
Soil	160-326	30-58.8	37-80	13-17	0-4.8	1.9-2.9	2.4-4.0
Grain	9-95	0.29-0.75	0.60-1.60	0.2-1.6	0-1.2	0-0.45	0.10-1.0
Straw	8.4-10.9	039-0.72	078-1.00	0.29-0.42	0-0.67	0-.40	018-0.55
Vegetables	0.6-85	0.1-0.5	0.4-0.8	0.72-1.3	0.2-0.06	0.10-0.50	0-0.14
Oil seeds	60-110	0.3-0.8	0.6-1.0	0.1-1.3	0.2-0.6	0.3-0.4	0.10-1.06
Normal range in soil	4000*	1000*	1000*	2-100**	0.1-40**	5-100**	0.1-10**

*Source: Atomic Energy Regulatory Board, Radiological Safety Division, Dept. of Atomic Energy, Govt. of India letter no AERD/RSD/28/2002/6007 on dated. July 26, 2002

**Source: P.C Srivastava and U.C. Gupta (1996): trace element in crop production, oxford and IBH publishing Co. Pvt. Ltd., New Delhi.

Table -7: Characteristics of Ash Pond effluent and well water collected from Ash bund Area of Chandrapur STPP and Bhusawal TPS

Parameters	A	B	C	D	E	F	G	H	Industrial Effluent Standards IS:2490	Drinking Water Standards IS: 10500
pH	8.28	8.14	8.19	8.11	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	349.0	360.00	140.00	75.00	100.00	-
TDS ”	610.00	467.30	587.90	451.70	531.0	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										
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	-	-

A : Water sample from Farmer's well Village- Chargaon collected on 15.02.97, Chandrapur
B : Drain water (Ash Effluent), well no. 5 discharge point collected on 15.02.97, Chandrapur
C : Water from Farmer's well near ash bund area collected on 19.08.97, Chandrapur
D : Water from ash pond effluent outlet, lagoon no. 1 collected on 19.08.97, Chandrapur
BDL- Below detection limit

E : Velhala Ash pond percolation well No. 3 collected on 10.12.98, Bhusawal
F : Velhala Ash pond percolation well No. 4 collected on 10.12.98, Bhusawal
G : Farmer's (Mr. Prahlad Patil) well water Village-Pimpalgaon Khurd on 08.02.99
H : Farmer's (Mr. V.M. Rane) well water Village: Pimpalgaon Khurd on 08.02.99

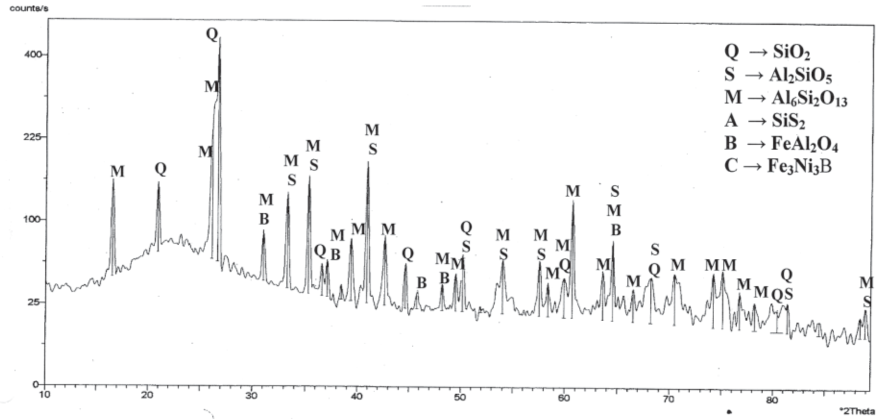


Plate-1: XRD PATTERN OF FLY ASH SAMPLE

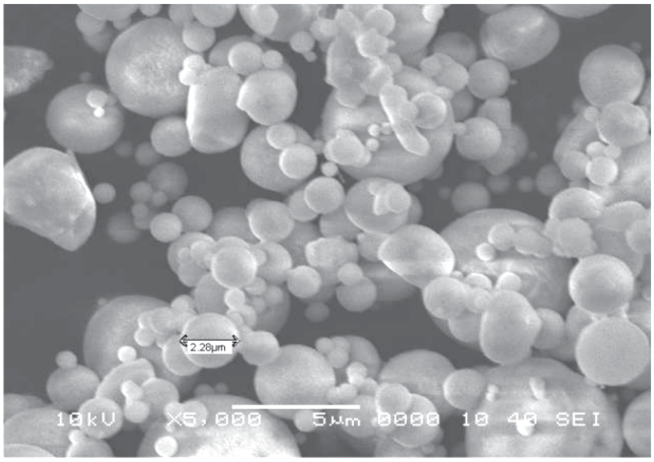


Plate-2: SCANNING ELECTRON MICROSCOPY OF FLY ASH

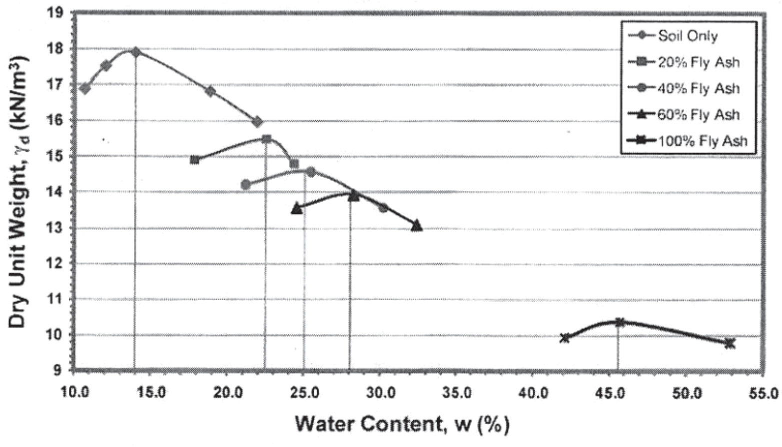


Plate-3: MOISTURE-DENSITY RELATIONSHIP OF THE FLY ASH-SOIL MIXTURES

WASTE MATERIALS - AN ALTERNATIVE TO CONVENTIONAL MATERIALS IN RURAL ROAD CONSTRUCTION

Dr Praveen Kumar[1] , Dr G D Ransinchungh R.N.[2] & Aditya Kumar Anupam[3]

ABSTRACT

India produces a huge amount of waste materials as byproducts from different sectors like industrial, construction, agricultural, etc. These waste materials if not deposited safely it may be hazardous. A large quantity of waste material is dumped at land filling site, which if investigated properly can be utilized in road construction sector. The utilization of these waste materials can be an economical and eco-friendly alternative in nearby areas for rural road construction. In India, research is currently underway to examine the potential for use of some locally available wastes in road construction. The results, to date, indicate that there is a wide scope for the use of such materials. However, in India, only a few materials have been used and that too on experimental basis. An attempt has been made in the similar directions for investigating the potential use of some industrial waste materials viz. cement and lime kiln dusts, quarry waste, slags, fly ash, construction & demolition wastes, rice husk ash bagasse ash, etc. for rural road construction.

1.0 INTRODUCTION

The quantities of wastes (such as cement and lime kiln dusts, quarry waste, slags, fly ash, construction & demolition wastes, rice husk ash bagasse ash, etc.) accumulating throughout the world are causing disposal problems that are both financially and environmentally expensive. Landfilling is becoming more expensive and, as sustainable management of resources is becoming a goal for many communities, the acceptance of landfilling or incineration is decreasing.

To deal with the growing disposal problem of these materials is an issue that requires co-ordination and commitment on the part of all parties involved such as government agencies, companies, the public and professionals. One method to reduce some portion of the waste disposal problem is by recycling and utilizing these materials in the construction of highways. However, such a use should not compromise the quality and performance of the highway infrastructure nor create environmental problems.

Nominal research has been done in India to determine the availability of feasible waste materials and the suitability of these materials for Indian roads. Yet the use of wastes would benefit the road sector by providing it with a cheap source of material and, in some cases, road construction companies may be able to charge a fee for suitably using waste materials that would otherwise require expensive treatment for disposal.

2.0 WASTE MATERIALS FOR ROAD CONSTRUCTION

The waste materials obtained from different sectors like industrial, construction, agricultural, etc. those which can be used as a substitute for conventional materials for rural road construction are discussed in following section.

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2. Assistant Professor, Indian Institute of Technology, Roorkee
3. Research Scholar

2.1 Industrial Waste

2.1.1 Cement and Lime Kiln Dusts: Cement kiln dusts are fine powdery materials, portions of which contain some reactive calcium oxide, depending on the location within the dust collection system where the material is collected. Some cement kiln dusts have been used with fly ash and aggregates to produce stabilized base course mixtures. Cement kiln dust has also been utilized as mineral filler in asphalt. Apart from cement production, the other principal uses of cement kiln dust are for stabilization of municipal sewage sludge and as a substitute for agricultural limestone. Because a number of cement kilns are burning hazardous waste as a supplemented fuel source, some investigation of fuel composition should be undertaken prior to using any given source of cement kiln dust.

2.1.2 Quarry Waste: Quarry waste consists mainly of the fines from stone washing, crushing, and screening at quarries, as well as some wet silty clay material from the washing of sand and gravel. These materials are not sized to meet specification requirements and are usually placed in ponds or stockpiled in a saturated condition. Consequently, these materials must be reclaimed and dewatered prior to use.

Quarry waste fines may be useful as fill or borrow material, as filler in concrete and flowable fills, in base or subbase stabilization, or as cement-stabilized base material for parking lots or low-volume roads.

2.1.3 Blast Furnace Slag: Blast furnace slag is an industrial by-product obtained in the manufacture of pig-iron in a blast furnace and consists mainly of silicates and alumino-silicates of lime and other bases. Blast furnace cement provides equal or improved performance over conventional Portland cement concrete. It has a low heat of hydration, good long-term strength gain, and high chemical resistance. When air-cooled slag is crushed and screened, the physical properties of slag make it particularly suitable as an aggregate. It breaks to give a consistent cubical shape and has a rough surface texture which gives better frictional properties and adhesion to bituminous and cement binder. It is thus widely used in civil engineering construction as a substitute for naturally occurring aggregates and also in all levels of road pavement structure.

2.1.4 Steel Slag: Steel slag, a by-product of the steel making process, contains considerable amounts of iron and its compressed void structure results in a very dense, hard material.

Steel slag, on the other hand, could become unstable because of its free lime (CaO) and free magnesia (MgO) with the consequent risk of expansion. Thus its use is severely limited in road construction and is virtually excluded from use as fill under structures. Steel slag, as construction aggregate, is recommended only in those situations where expansion is unlikely, as in the case of dense bitumen macadam, or in the places where expansion does not cause a serious problem. Their main use therefore is in the upper bituminous layers of the road structure or in surface course.

2.1.5 Fly Ash: Pulverized Coal is being used as fuel in thermal power generation units to meet the growing demands of electricity. In India, approximately seventy percent of the total electricity is produced using this method. Huge quantities of coal ashes, in form of fly ash and bottom ash, are generated in the process as a waste and these are collected in ponds in slurry form which is known as pond ash.

The estimated production of pond ash in India at present is about 70 MT which is expected to cross 100 MT by the year 2000. This huge quantity of ash is creating problems of disposal and creating environmental pollution.

To overcome these problems, various processes for utilization of fly ash have been developed by scientists/ engineers in India and abroad, but its consumption is still quite low. Viewing it as an issue of disposal of fly ash to overcome environmental pollution, efforts need to be made in development of applications for bulk utilization of the enormous amount of ash in production continuously. R&D work has been initiated for satisfactory & useful utilization of pond ash.

2.2 Construction Waste

2.2.1 Building Construction and Demolition Debris: Although precise figures are not readily available, it is estimated that at least 20 to 30 million tons per year of construction and demolition (C&D) debris are generated in the United States (NCHRP, 1994). C&D debris consists largely of wood and plaster, but also includes concrete, glass, metal, brick, shingles, and asphalt. Portions of this debris that are reclaimed, crushed and processed into aggregate include concrete bricks, glass, and old asphalt. Recycling of C&D debris is done regularly at numerous processing locations around the country, mainly in large metropolitan areas. To be marketed effectively, the processed material must be free of deleterious components such as wood, drywell and plastic, and must be capable of meeting gradation and other aggregate quality requirements. Wood and tree stumps can also be separated, shredded, and converted into wood chips. The wood chips can be used as fuel, landscaping material, or as a bulking agent in sludge composting.

Many of the materials dumped at C&P landfills are not accepted at sanitary landfills and cannot be composted. Although C&P debris is intended to be inert and essentially inorganic (except for wood), potential problems can occur if illegal dumping is not prohibited. Possible contaminants that could be included in C&P debris are sewage sludge, which cause odors, and asbestos, which is hazardous.

2.2.2 Reclaimed Asphalt Pavement: It is estimated that approximately 50 million tons (NCHRP, 1994) of asphalt paving material in US are currently being milled annually. Much of this material is returned to procedures' yards for use in paving mixes. In order to maintain mix temperatures satisfactorily, only about 20-50 percent of all the milled asphalt paving material is able to be recycled into hot-mix asphalt paving mixtures. Reclaimed Asphalt Pavement (RAP) can be recycled into hot mixes, cold mixes, or in-place mixes. RAP can also be used in other highway uses, as in unbound aggregate base and subbase, stabilized base course, shoulder aggregate, and open-graded drainage courses.

2.2.3 Reclaimed Concrete Pavement: The recycling of concrete pavements began about 20 years ago. Early efforts reused concrete paving rubble as an unbound aggregate base and in asphalt base and binder courses. Within a few years, recycled concrete aggregate was being used in asphalt-wearing surfaces. The FHWA coordinated research among state highway agencies to evaluate the suitability of RCP as an aggregate source in concrete mixes. This work included laboratory studies, mix design testing, and performance evaluation of RCPs. These studies (2) have proven that recycled concrete aggregates produce strong, durable concrete suitable for use in pavements, even when RCP aggregate is derived from distressed paving concrete (D-cracking or alkali-silica reaction).

Over the years, the recycling of concrete pavements has become more cost competitive with the development of improved methods and equipment for breaking concrete pavements, removing the steel from the broken concrete, and crushing slabs with reinforcement. In many instances, concrete pavement recycling is a viable alternative to complete reconstruction, concrete pavement rehabilitation (CPR), or an overlay of an existing deteriorated pavement. Existing concrete pavement must be considered as a resource that can and should be recycled or reused in some application, much in the same way as asphalt pavement recycling is now commonly practiced.

2.3 Agricultural Waste

2.3.1 Rice husk ash: In road construction projects, soil or gravelly material is used as the road main body in pavement layers. To have required strength against tensile stresses and strains spectrum, the soil used for constructing pavement should have special specification. One of the suitable methods to achieve these aims is using lime. Since 1945, the technique of soil treatment with lime has been in use. In fact, the reaction between soil and lime is performed very slowly. Therefore, activating the reaction of soil with lime by some additive is necessary. Rice husk is an agricultural waste obtained from rice milling. India alone produces around 120 million tones of rice paddy per year, giving around 24 million tones of rice husk per year. Rice husk ash (RHA) includes a huge amount of silica with high specific surface that is very suitable for activating the reaction of soil and lime. This matter is not suitable for cattle feeding and is non biodegradable. Thus, using RHA as an additive seems to be economical particularly in regions having high production capacity.

2.3.2 Bagasse ash: Bagasse ash is an agricultural by-product of sugar manufacturing. When juice is extracted from the cane sugar, the solid waste material is known as bagasse. After the extraction of all economical sugar from sugarcane, about 40-45% fibrous residue is obtained, which is reused in the same industry as fuel in boilers for heat generation leaving behind 8 -10 % ash as waste, known as sugarcane bagasse ash (SCBA). This ash is considered as waste and disposed in an environmentally debilitating manner. After the extraction of all economical sugar from sugarcane, about 40-45% fibrous residue is obtained, which is reused in the same industry as fuel in boilers for heat generation leaving behind 8 -10 % ash as waste, known as sugarcane bagasse ash (SCBA). The SCBA contains high amounts of un-burnt matter, silicon, aluminium and calcium oxides. It is a very valuable pozzolanic material if carbon free and amorphous ash could be obtained by further combustion. A few studies have been carried out on the ashes obtained directly from the industries to study pozzolanic activity and their suitability as binders, partially replacing cement.

3.0 INVESTIGATING THE POTENTIAL USE OF WASTE MATERIALS

3.1 Building Construction and Demolition Debris

In the present work, use of recycled aggregate from building waste as base course and sub-base course has been studied in order to reduce the material transport cost and disposal cost. The properties of conventional aggregates were compared with recycled aggregate as shown in Table 1.

Table 1. Laboratory results for different types of Building Waste Materials

Description of material	Specific gravity	Water absorption (%)	Aggregate crushing value (%)	Aggregate impact value (%)	Fineness modulus
Conventional Aggregate	2.85	1.2	18.59	12.46	6.27
Recycled Aggregate	2.48	3.8	27.13	24.62	6.77

Based on the experimental results obtained, it can be concluded that the recycled aggregate can be effectively used as a road material in different layers as the properties satisfying the MOSRT&H requirements. Recycled aggregates found to be relatively soft compared with conventional aggregate and can be used as a sub-base material but not in base course and wearing course. Water absorption of waste material is found to be high compared with conventional aggregate. The results of recycle aggregate are found to be within the limits as per MOSRT&H specifications.

3.2 Fly Ash

The chemical, physical and engineering properties of ash depends on the type and source of coal used, method and degree of coal preparation, cleaning and pulverization, type and operation of power generation unit, ash collection, handling and storage methods etc. So the properties of fly ash vary from plant to plant and even within the same plant.

The fly ash used in the study was brought from National Thermal Power Station situated at Ghaziabad which was available free of cost. Fly ash is classified as silts of low compressibility (ML). The physical and chemical properties of fly ash are given in Table 2 and Table 3 respectively.

Table 2. Physical Properties of Fly ash

Properties	Test Value
Specific Gravity (G)	2.16
Fineness by Sieving Sand particles (%)	3.5
Silt particles (%)	95.5
Clay particles (%)	1.0
Proctor OMC (%)	22.0
Maximum dry density (gm/cc)	1.4

Table 3. Chemical Properties of Fly ash

Compound	%
SiO_2	58.78
Fe_2O_3	9.31
Al_2O_3	26.92
CaO	1.77
MgO	0.68
N_2O	0.28
K_2O	1.44
Loss on Ignition (%)by weight	0.72

In order to find the suitability of fly ash used in this study, it was stabilized with soil and the strength characteristic in terms of CBR was determined in laboratory. The physical properties of soil used for stabilization is given in Table 4. The results for OMC, MDD and CBR for soil, fly ash and soil admixed with fly ash are shown in table 5.

Table 4: Properties of Soil

Property	Value
Classification as per Revised PRA	A-3
OMC (%)	13.5
Maximum Dry Density (gm/cc)	1.8
Specific Gravity	2.65
Uniformity Coefficient, Cu	2.19
Coefficient of Curvature, Cc	0.90
Liquid Limit (%)	Non Plastic
Plastic Limit (%)	Non Plastic
Plasticity Index (%)	Non Plastic

Table 5. OMC, MDD and CBR of various materials

S.No.	Type of Material	Optimum Moisture Content (%)	Maximum Dry Density (gm/cc)	CBR (%)
1	Soil	14.0	1.85	11.42
2	Fly ash	22.0	1.43	15.71
3	75% Fly ash + 25% Soil	18.5	1.59	18.57

As shown in the table, admixing of the fly ash in the soil increases the CBR as compare to the CBR of soil without admixture. Hence it can be conclude that the fly ash can be satisfactorily used as an soil stabilizing agent for subgrade in road constructions.

3.3 Steel slag and Blast furnace slag

Steel slag is produced during the manufacturing of steel. To produce steel, it is necessary to further refine molten iron to remove carbon and make additions of materials such as maganese, silicon, chrome and titanium. This refinement stage imparts the properties such as strength, hardness, toughness, and flexural strength. Air Cooled Blast Furnace Slag (commonly known as BF slag) is produced by putting the molten slag into a pit where it is allowed to cool slowly in open air. Crystallization takes place resulting in materials like a fine-grained igneous rock. Because of its similarity to igneous rocks, it has found extensive use as concrete aggregate, road surfacing stone and road base course material.

Typical chemical analysis and physical properties as tested in laboratory for steel slag and blast furnace slag aggregates as obtained from Rourkela Steel Plant are given in Table 6 and Table 7 respectively.

Table 6. Chemical Analysis of Steel and Blast Furnace Slag

Compound (%)	Blast Furnace Slag	Steel Slag
SiO_2	31-37	12-18
CaO	26-33	30-50
MnO	Upto 6	8-14
FeO	Upto 2.5	15-30
MgO	4-10	2-8
$Al\text{-}_2O_3$	22-27	2.5

Table 7. Physical Properties of Steel and Blast Furnace Slag

Sl.No.	Physical Properties	Test Method	Steel slag	Blast Furnace Slag	Requirements (MOST specifications)	
					Subbase/ Base Course	Bituminous Course
1.	Aggregate Impact Value	IS:2386 (Pt. IV)	8-11%	7-25%	40% Max.	30% Max.
2.	Los Angeles Abrasion Value	IS:2386 (Pt. IV)	8-10%	28-32%	50% Max.	35% Max.
3.	Flakiness Index	IS:2386 (Pt. I)	12%	12%	15%	35%
4.	Elongation Index	IS:2386 (Pt. I)	8%	9%	30%	30%
5.	Water Absorption	IS:2386 (Pt. III)	1-1.6%	1.5-3%	-	2%
6.	Specific Gravitykg/m^3	IS:2386 (Pt. III)	3220	2650	-	-
7.	Bulk Density kg/m^3	IS:2386 (Pt. III)	2100	1800	-	-

Based on extensive laboratory and field investigations, it is concluded that steel plant slags possess all the physical/engineering and chemical characteristics required of a good road construction material. The granulated blast furnace slag, though does have self-cementing properties, its cementing properties can be activated by an additive like lime. The BF slag and steel making slag possess good mechanical interlock through compaction, but steel-making slag should be used after proper weathering as it expands during hydration.

3.4 Rice Husk Ash

Rice husk ash is a predominantly siliceous material obtained after burning of rice husk in a boiler or an open fire. Lime reactivity test conducted on this ash indicate the fully burned rice husk ash exhibits greater reactivity. This waste material having pozzolonic properties can be utilized in the stabilization for road construction. For this study, rice husk ash was obtained from paddy mill, Roorkee. It was fine grained siliceous in nature light weight and grey in color. The physical properties are given in Table 8.

Table 8. Properties of Rice Husk Ash

Sr. No.	Properties	Values
1	Sio_2 (%)	72.24
2	CaO (%)	4.12
3	MgO (%)	1.7
4	$Fe_2O_3 + Al_2O_3$	7.2
5	Specific Gravity	1.87
6	Lime Reactivity (kg/cm^2)	34

The suitability of rice husk ash as a stabilizing agent was tested using a clayey soil having properties as given in Table 9. The strength of soil stabilized with RHA was determined in terms of CBR and the results are presented in Table 10.

Table 9. Physical Properties of Soil

Sr. No.	Properties	Values
1	Specific Gravity	2.68
2	Liquid limit (%)	41
3	Plastic limit (%)	24
4	Plasticity index	17
5	Classification (As per IS)	Low compressibility inorganic clay
6	Classification (As per USRPA)	A-6

Table 10. OMC, MDD and CBR of Soil-RHA Admixture

S.No.	Type of Material	Optimum Moisture Content (%)	Maximum Dry Density (gm/cc)	Soaked CBR (%)
1	Soil	16.0	1.82	1.43
2	Rice Husk Ash	17.5	1.74	2.80
3	Soil + 5% RHA	18.5	1.69	3.20
4	Soil + 10% RHA	20.0	1.64	4.80
5	Soil + 15% RHA	22.0	1.61	7.0
6	Soil + 20% RHA	23.0	1.58	9.5
7	Soil + 25% RHA	24.5	1.56	12.0
8	Soil + 30% RHA	26.0	1.51	12.5

The results shows that the maximum dry density decreases to 1.51 gm/cc (from 1.82 gm/cc for neat soil) when 35 % RHA is added in soil. It is attributed to the lower value of specific gravity of RHA. The results of soaked CBR shows that the CBR value increases from 1.43% to 12.5 % for the soil admixed with 30 % RHA. This shows remarkable improvement of CBR values in stabilized soil with 25 % of RHA can be successfully used in sugrade / subbase course for pavement construction.

4.0 USE OF STEEL INDUSTRY SLAG IN BITUMINOUS LAYERS

To determine the suitability of Steel Industry Slag in Bituminous Layers, a study was conducted at IIT Roorkee.

Results of Marshall Test in case of BM, SDC and Bituminous Concrete for different blends have been given in Tables 11, 12 & 13.

Table 11. Bituminous Mix Properties for Bituminous Macadam at Optimum Bitumen Content

SN	Mix Properties	SMS	BFS	Sand Stone	SMS(70%)+ Sand Stone (30%)	BFS(70%) +Sand Stone (30%)	Requirements as per MORTH specifications
1	Marshall Stability (kg)	1720	1020	550	1045	1470	Not Specified
2	Flow value(mm)	3.01	2.6	4.05	3.65	4.22	-
3	Air Voids(%)	3.4	3	5.7	3.3	3.5	-
4	VFB(%)	77	80	61	75	68	-
5	Optimum Binder Content (%)	3.77	3.63	3.82	3.72	3.73	-

Table 12. Bituminous Mix Properties for Semi Dense Concrete at Optimum Bitumen Content

SN	Mix Properties	SMS	BFS	Sand Stone	SMS(51%)+ Sand Stone (49%)	BFS(51%) +Sand Stone (49%)	Requirements as per MORTH specifications
1	Marshall Stability (kg)	1180	900	820	1110	1000	820 minimum
2	Flow value(mm)	2.54	3.06	3.75	3.5	3	2-4
3	Air Voids(%)	3.9	5	4.7	4.9	5.0	3-5
4	VFB(%)	75	60	70	71	66	65-75
5	Optimum Binder Content (%)	4.52	4.75	4.85	4.80	4.78	4 minimum

Table 13. Bituminous Mix Properties for Bituminous Concrete (Dense Graded) at Optimum Bitumen Content

SN	Mix Properties	SMS	BFS	Sand Stone	SMS(50%)+ Sand Stone (50%)	BFS(50%) +Sand Stone (50%)	Requirements as per MORTH specifications
1	Marshall Stability (Kg)	1200	1025	1000	1250	1110	820 Minimum
2	Flow Value (mm)	3.8	3.8	4	3	3.1	2-4
3	Air Voids (%)	3.96	3.1	4.1	4.2	3.2	3-5
4	VFB (%)	81	75.5	75	75.5	78	65-75
5	Optimum Binder Content (%)	5.63	5.22	5.42	5.2	5.38	4.5 Minimum
6	Retained Marshall Stability (Kg)	950	905	850	1000	1000	-
7	Loss of Stability (%)	20.8	9.9	15	18	11	25 Maximum

5. 0 EXPERIMENTAL TEST TRACKS CONSTRUCTED USING STEEL INDUSTRY SLAG

Some test tracks have constructed using steel industry slag in different parts of the country by Central Road Research Institute.

It includes

i) A-P Road using Granulated Blast Furnace Slag from Visakhapatnam Steel Plant.

ii) In campus Test Track in Bokaro using Blast Furnace Slag and Steel Making Slag from Bokaro Steel Plant

iii) Jaraikala Bandamunda Road using Steel Industry Slag from Rourkela Steel Plant.

These were the pioneer works initiated by CRRI. This being used in different parts of the country for construction of roads which are near to steel plant sites.

6.0 CONCLUSIONS

The physical, chemical and strength characteristics of various waste materials like building construction and debris (Recycled aggregates), Fly ash, Steel & Blast furnace slag and Rice husk ash were tested in laboratory and the results were found to be within the specified limits as per MOSRT&H. Salient outcomes of the study are enlisted in following section.

1. Recycled aggregates found to be relatively soft compared with conventional aggregate and can be used as a sub-base material but not in base course and wearing course. Water absorption of waste material is found to be high compared with conventional aggregate. The results of recycle aggregate are found to be within the limits as per MOSRT&H specifications.

2. Admixing of the fly ash in the soil increases the CBR as compare to the CBR of soil without admixture. Hence it can be conclude that the fly ash can be satisfactorily used as an soil stabilizing agent for subgrade in road constructions.

3. Based on extensive laboratory and field investigations, it is concluded that steel plant slags possess all the physical/engineering and chemical characteristics required of a good road construction material.

4. The CBR increases on addition of RHA to soil from 1.43% to 12.5%, there by confirming the use of RHA as an soil stabilizing agent for sub-grade in road construction.

5. Steel Industry Slag is not a waste material now. It has proved to be a good material for road construction.

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USE OF NON-CONVENTIONAL MATERIALS FOR THE CONSTRUCTION OF LOW-VOLUME ROADS

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ABSTRACT

The quality of materials e.g. soil and aggregate is of immense importance for the design life and also for the performance characteristics of unbound layers of road pavements. Sometimes, the desired materials are not available in the locality and are imported from far off places. This increases the transportation cost and in turn the cost of construction goes up tremendously. Keeping in view the emphasis put on road construction in the recent times in India through Pradhan Mantri Gram Sadak Yojana (PMGSY) and National Highways Development Project (NHDP), there is an immediate need to explore the possibilities of using the locally available materials for construction of unbound pavement layers. The engineering properties of these materials might not be suitable for design and construction according to the prevailing code of practices and thus it is necessary to study their properties in detail and explore the possibilities of using them with or without addition of other materials. The paper suggests a framework for preparing a database on the availability of materials in a locality with all details such as quantity available, engineering properties and how they can be used in pavement construction. Report on a preliminary study carried out to identify locally available construction materials in a few selected districts in Rajasthan has been included in the paper. To demonstrate the usage potential of locally available materials, laboratory investigations were conducted on slate stone dust collected from Neemrana Block of Alwar District, Rajasthan. Based on the study, it has been observed that this material which is abundantly available in the block could be used effectively for the construction of unbound layers of low volume road. The results on the use of nano-silica with construction and demolition materials on the improvement of engineering properties have also been reported in this paper.

Key words: Locally available materials, slate stone dust, low volume roads, construction and demolition materials, nano-silica

1. INTRODUCTION

The transportation infrastructure system is one of the main investments every modern society must make for their economic and social development. In India, a special drive has been taken at the beginning of the new millennium to improve the road and highway systems in the country. Accordingly two ambitious projects have been initiated with the development of National Highways Development Projects (NHDP) and the rural roads development programme, popularly known as the Pradhan Mantri Gram Sadak Yojana (PMGSY). These programmes are likely to continue for a long time as the targets would keep on changing with the achievement of a set of targets. This will require huge quantities of pavement construction materials. It is well-known that naturally occurring aggregates used for road construction are depleting rapidly. They are extracted from natural

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rocks and possess certain engineering properties. Quite often these materials are not available locally in sufficient quantities and are to be brought from far off places which increases the transportation cost. It increases the project cost substantially. During the last few decades research has been conducted on various aspects of low volume roads resulting in innovative and unconventional approaches of road construction. It has been observed that it would be economical to use locally available materials in the construction of low-volume roads. In most of the cases such aggregates do not meet the standard specifications and thus there is reluctance by the field engineers to use these materials.

One potential area of usage for locally available material in flexible pavement construction is in the unbound layers of the pavements such as base, sub base that rest on compacted soil layer called the subgrade. The performance of unbound granular pavement layers depends greatly on the properties and quality of the aggregates used. One of the factors contributing to distresses in both rigid and flexible pavements is the poor performance of unbound layers resulting in reduced life and costly maintenance. The characteristics of unbound layers depend on shear strength, density, gradation, fines content, moisture level, particle angularity and surface texture, degradation during construction and under repeated loads, freeze-thaw cycles and drain-ability. Thus the selection of material for construction of unbound granular layers plays a prominent role in the pavement construction and its performance. However, the quality of locally available aggregate or borrowed aggregate can be modified by using the stabilization technique, which results in lesser thickness of unbound layer and better pavement performance. The material used for construction of unbound granular layers is many a time borrowed from other places thereby increasing the cost of pavement construction. This is because of the impression that locally available materials are not generally good for usage in pavement construction. Though this assumption is valid in many occasions, is not always true. Also, when the quality of locally available aggregate or borrowed aggregate does not meet the standard specification, their properties can be modified for usage by using stabilization techniques resulting still resulting in considerable cost savings.

2. ALTERNATIVE MATERIALS FOR ROAD CONSTRUCTION

Crushed igneous rocks are ideal as pavement material due to their high strength and other engineering properties. However, they are not easily available everywhere, and thus not always economical because of high transportation cost. Thus there is a need to explore the possibilities of using locally available materials although they might have less strength than traditional materials and might not be suitable according to the standard tests specified in the codes of practices. The problem of locally available material falling short of the standard specifications can be tackled in two ways. First, their properties can be improved by modifying the local materials by the addition of a stabilizing agent. Otherwise, the specifications of their usage can be modified i.e. they can be specified to be used in traffic conditions that could be catered to by these materials. The greatest potential for saving can be achieved by making use of untreated local materials. One such solution is using locally available materials in the construction of unbound layers of low volume roads. The availability of the locally available materials (marginal materials) in the different parts of India could resolve the problem of materials scarcity for the construction of low volume roads and substantial reduction in the construction cost can be achieved by utilizing such materials. Moreover, the use of the locally available materials in the pavement construction will solve the problem of the various industries that are simply piling their waste materials in their surrounding region.

Research has also been conducted on sand, which is abundantly available in the country, to use for road construction. The detailed survey of soils and road construction materials carried out in sandy areas has shown that a variety of materials such as *dhandla* (a calcareous material), kankar, soil-gravel mixes and bentonite (heavy clay) are found in many locations. All these materials have been tested for being used as subbase/ base materials and were found to be suitable. Suitability of desert sand cement mixes for base course in highway pavements was studied by Al-Aghbari and Dutta (2001). Utilisation of poorly graded river sand and flyash in Sand-Asphalt-Sulphur (SAS) Paving mixes was studied by Mazumdar and Rao (1994). Beach sand was used for SAS paving mixes by Mazumdar and Havanagi (1995). Soft aggregates of Mizoram were tested with lean cement to achieve acceptable strength for use as base and sub-base by Zoramliana et al, 1998 with satisfactory results.

In India, efforts have been made to use fly ash, a bio-product of thermal power stations, for the construction of roads (Narasimha and Sundarrajan, 2004 and IRC; 1976). It can be used as filler material in embankment and also as a base/ subbase course. Subbase course can be constructed using pond ash or bottom-ash. Also the pozzolanic property of fly ash enables it to be used as an alternative binder. The coarser fly ash can be used as filler material and the finer ash can be used for replacement of sand and cement. Several demonstration rural road projects have been constructed close to major thermal power stations. For the construction of PMGSY roads it has been made mandatory to explore the possibility of using fly ash if the site is within a radius of 100km from a thermal power station. Similarly, steel slag, a waste product of steel industries, can be used as a pavement material in a variety of ways, especially as base or sub-base (Kumar et al. 2006, Bhadra and Sandhwar, 2002).

With the emphasis on sustainable development there is growing pressure to investigate the viability of reuse of all categories of waste materials such as construction and demolition (C&D) materials. They are obtained with the demolition of buildings and structures. The urgency of using recycling C&D material has increased because of scarcity of natural aggregates and other environmental concerns. Although there exists some concerns at the government levels to recover C&D waste to a certain extent, there is still tremendous scope to recover them and reuse as construction material. Central Pollution Board reported in 2004 that solid waste generation in India was about 48million tons per annum and more than 25 percent of this is from construction industry which consists of about 7-8million tons of concrete and brick waste. The waste quantities are estimated to reach to the level of at least 65million by 2010 (Kumar and Gaikwad, 2004). The concrete industry uses approximately 10 billion tons of sand and natural rock worldwide, and more than 10 billion tons of construction and demolition waste are produced every year (Mehta 2002). The European Union produces approximately 200-300 million tons per year of construction and demolition waste, which is roughly equivalent to 0.5-1 ton per capita per year (Zega C J and Maio A A D, 2011). Studies have been carried out on the different properties of recycled concretes with crushed waste concrete of different origin and highly satisfactory results regarding their strength properties have been reported (Topeu and Sengel 2004; Katz 2003; Poon et al. 2004). C&D is particularly a very promising source of aggregate as 75 percent of any typical concrete is made of aggregates and if it could be recycled it reduces management and maintenance costs of dumpsites and landfills and also transportation cost.

The possibility of using recycled concrete aggregates and crushed clay bricks as aggregates as unbound subbase material was investigated by Poon and Chan (2006). Laboratory tests were conducted by using different blending percentages of recycled concrete aggregate and crushed brick. The use of 100 percent recycled concrete aggregates was found to increase the optimum moisture content and decrease maximum dry density of the subbase material, compared to natural subbase materials. In addition, the replacement of recycled concrete aggregates by crushed clay bricks further increased the optimum moisture content and decreased the maximum dry density. It was possible to produce a soaked CBR value of at least 35 by blending concrete aggregates and crushed clay bricks appropriately. An experimental road was constructed in Italy (Portas, 2004) with a subgrade consisting of demolition waste material. The mechanical behaviour and reliability of subgrade layer was investigated and the performance of the road was monitored both in the short and long terms. It was concluded that further research is needed to understand the chemical, physical and mechanical behavior of C&D waste materials. The compaction characteristics and bearing capacity of recycled materials was studied by Rabaiotti and Caprez (2004) and it was concluded that there was no easily definable relationship. Performance of overburnt distorted bricks as aggregates in pavement works was studied by Mazumdar et al. (2006). Routine laboratory tests had shown that the aggregates are stronger, less absorptive, and denser than the ones picked form type-A bricks. Some of the problems associated with C&D are: low specific gravity, higher water absorption, lower level of strengths and durability, lack of strong bond with binder. However, properties of C&D can be improved by treating it with suitable organic and inorganic compounds. Research has been going on to improve the engineering properties of C&D by adding nano-materials such as Nano-silica.

3. DIFFICULTIES IN THE USE OF ALTERNATIVE MATERIALS

Even though the use of locally available materials has been understood by the professionals, a few factors pose a challenge in their use. These factors include:

- Lack of information about availability: Quite often the designers are not aware of the availability of suitable alternative materials in the locality in the absence of any database.

- Standards and specifications: Enough research has not been carried out on the performance of roads constructed with alternative materials to develop standards and specifications.

- Uncertainty and lack of confidence: There is reluctance by the designers and field engineers to use alternative materials as they are not certain about the outcome. The reason is that the standard methods of test often do not provide true assessment of the performance of the material.

- Lack of initiative: Even though the funding agencies are very supportive for the use of locally available alternative materials for pavement construction, very few initiatives have been taken by the engineers to implement such an initiative. One of the reasons has been frequently mentioned that the government engineers are quite busy in implementing time-bound projects and thus they do not have much time left for experimentation. Thus initiatives are rarely taken to try new materials for road construction.

- Public perception of roads: The construction of high-quality PMGSY roads in the rural areas has made the general public quite aware about road construction technologies and the materials that are being used for construction. Thus to start with there may be objections from them if any alternative material is used for construction of roads. They might have the perception that roads constructed with alternative materials are not of high quality.

4. DEVELOPMENT OF FRAMEWORK FOR DEVELOPING DATABASE OF IDENTIFYING ALTERNATIVE MATERIALS

All materials available naturally or otherwise may not be suitable to be used for road construction. The key engineering factors and materials requirements are shown in Table-1 (Cook and Gourley, 2002). A procedure has to be developed to identify and utilize locally available materials for road construction. In this paper, a suggestion has been made to develop a systematic approach for identification of locally available materials for the construction of roads in a specific region. The steps involved in the suggested approach are being shown in Fig-1. To develop a database on the availability of materials in a given region (may be a block as the unit to start with) first of all a reconnaissance survey needs to be carried out to locate the sources of the materials with the approximate estimate of the quantity available. This data will be collected from secondary sources such as Geological Survey of India and remote sensing database and with the interaction with the government officials, contractors and others involved in the developmental activities in the region.

Table 1. Fundamentals of Selection of Alternative Materials (Source: Cook and Gourley, 2002)

Key Engineering Factor	Material Requirements
Strength	Aggregate particles need to be load resistant to any loads imposed during construction and the design life of the pavement
Mechanical stability	The aggregates as a placed layer must have a mass mechanical interlocking stability sufficient to resist loads imposed during construction and the design life of the pavement
Durability	Aggregate particles need to be resistant mineralogical change and to physical breakdown due to any wetting and drying cycles imposed during construction and the design life of the pavement.
Haul distance	Reserves must be within physically and economically feasible haulage distance.
Placeability	Material must be capable of being placed and compacted by the available plant
Environmental Impact	Material reserves must be capable of being won and hauled within any governmental impact regulations.

Extensive survey need to be conducted to confirm or verify the result of information gathered from various sources. Extensive literature survey and interaction with local level officials need to be conducted to know the engineering properties of the materials and their suitability as pavement materials. If it is found that some test road sections have already been constructed with these materials, details about the performance characteristics of the pavement is to be collected. If it is not available from the secondary sources, a study is to be conducted to find out the details about the construction and then the performance in terms of distresses and structural characteristics. If the materials are found to be of inferior quality, possibilities of improving the engineering characteristics by adding other material/ admixtures with it must be studied. It is also necessary to explore the possibilities of replacing certain percentage of standard aggregates with the locally available materials for road construction. However, suitability of any material to be used for pavement construction will be determined after carrying out economic evaluation. Finally a GIS map is to be prepared showing all the potential locally available materials sites, with their quantities, engineering properties and cost so that while designing a road pavement, the engineer would be able to consider all the possible alternative materials so as to arrive at the lowest cost pavement. The steps involved are as given below:

- Locate the source of the marginal materials in a particular region from secondary sources such as Government departments, Geological Survey of India and Remote Sensing organization.

- Conduct extensive survey to confirm or verify the information gathered from secondary sources. Also try to locate if other sources are available in the region. Assess the quantity of materials available, thickness of overburden, workability and the thickness of the exploitable layers.
- Conduct exploratory pitting and conduct a few basic field tests to assess the quality of the materials. Collect samples at a few scattered locations to conduct laboratory tests.
- Carry out standard laboratory tests to find out the basic engineering characteristics to be used as pavement material.
- If not found suitable, explore the possibilities of improving the characteristics by mixing with other materials or additives.
- Develop a laboratory testing protocol that allows selection of the optimum modifier/ material content for the unconventional mixes prepared with locally available marginal materials, proposed to be tried for various layers of a multilayered flexible pavement, along with characterization of different materials used.
- Conduct economic analysis of all the possible mixes.
- Develop a GIS map of the region showing the locations of availability of materials with quantities and engineering characteristics. Brief information about how to use the material for pavement construction is to be included.
- Construct test tracks (composite pavement section as well as conventional multilayered structure, as control section) and performance monitoring of the test tracks under simulated/ real life loading (both static & dynamic) conditions using standard instrumentation over a period of time and analysis of the collected data.
- Develop Mechanistic Empirical (M-E) pavement structural design process for the multilayered composite pavement structure making use of the laboratory and field observations.
- Develop the specifications and user friendly nomographs for design and to check the economic viability of the proposed unconventional pavement structure vis-à-vis conventional multilayered pavement structure.

5. PRELIMINARY SURVEY FOR LOCALLY AVAILABLE MATERIALS FOR PAVEMENT CONSTRUCTION IN RAJASTHAN

To locate the various potential sources of locally available materials a survey has been conducted in twelve districts of Rajasthan through the state PWD Assistant Engineers and Junior Engineers. A questionnaire was prepared and circulated among the Engineers to indicate the possible information about the locally available materials in their region. Twenty one possible materials have been identified on the basis of preliminary survey. It may be observed that most of the locally available materials have not been tried for road construction as yet and there is a need to carryout studies to determine engineering properties of each one of them to identify the aggregates that could be used for pavement construction.

The outcome of the preliminary survey conducted for identifying locally available materials is shown in Table1. A few materials such as muroom and kankar, available in some part of Rajasthan, are widely used for the construction of roads in many parts of India. Flyash has also being used in some of the states in India. Some materials such as slate stone dust, kota stone slurry, sandstone, blown up sand that are mainly available in the Rajasthan can be utilized for the various layers of the pavement with or without stabilizing agent. However, extensive research has to be carried out in this particular direction for utilizing these materials. Utilization of such materials not only will reduce the shortage of materials but also will reduce the cost of construction.

Table 2. List of locally available materials in different districts of Rajasthan

S.No.	Name of Locally Available Material	Place	District	Present used (Yes/No)	Remark/Used
1	Slate Stone Dust	Nimrana Balotra	Alwar Barmer	No No	Dumped
2	Blown up Sand	Balotra Bikaner	Barmer Bikaner	No No	
3	Lignite Mixed Overburden	Barmer	Barmer	No	
4	Sandstone	Siwana Baseri Hindaun	Barmer Dholpur Karuli	Yes Yes No	WBM GSB & WBM
5	Gypsum	Barmer	Barmer	No	
6	Dhandla Stone	Barmer	Barmer	Yes	Subbase
7	Crusher Dust	Barmer Luni Pali Sirohi	Barmer Jodhpur Pali Sirohi	Yes Yes No No	Filler Filler
8	Lime Stone	Kolayat Hindaun	Bikaner Karuli	Yes No	Not mentioned
9	China Clay (Waste Product)	Bikaner	Bikaner	No	Dumped
10	Glazed and Unglazed Ceramics Tiles and Slurry	Bikaner	Bikaner	No	Dumped
11	Marble Stone Dust	Bikaner Sirohi	Bikaner Sirohi	No No	
12	Muroom	Baseri Hanumangarh Jodhpur Pali	Dholpur Hanumangarh Jodhpur Pali	Yes Yes Yes Yes	Shoulder Preparation Not mentioned Shoulder Preparation Not mentioned
13	Over Burnt Brick (Jhama)	Suratgarh Hanumangarh	Ganganagar Hanumangarh	No Yes	 Not mentioned
14	Fly Ash	Suratgarh	Ganganagar	No	
15	Ballast/Grit	Jalore Pali Phalodi, Mandore Reodar	Jalore Pali Jodhpur Sirohi	Yes Yes Yes No	GSB GSB WBM
16	Gravel/Kankar	Bikaner Jalore Nagaur Phalodi,Bilara Pali	Bikaner Jalore Nagaur Jodhpur Pali	No Yes No Yes Yes	 Shoulder Prepartion Subgrade & Shoulder Sub base, Base
17	Stone Quarry Rubbish	Jalore Merta City	Jalore Nagaur	No No	
18	Granite Cutting Dust	Jalore	Jalore	No	
19	Over Burnt of Lime Kiln	Bilara,Bhopalgarh	Jodhpur	Yes	Not mentioned
20	River Sand	Luni,Mandore Sojat	Jodhpur Pali	Yes Yes	Subgrade & Shoulder Not mentioned
21	Kota Stone Slurry	Pali	Pali	No	

6. PRELIMINARY LABORATORY INVESTIGATIONS ON TWO SELECTED MATERIALS

6.1 Test on slate stone

A small study was taken up to explore the possibility of using slate stone dust for road construction. The material is abundantly available in the Neemrana Block of Alwar District, Rajastha. This stone dust is obtained as a waste product after cutting of slate stones. There are many such cutting plants in the area and the wastes are simply dumped in vacant spaces. Apparently it is sedimentary rock and by preliminary tests in the field was found to be brittle in nature and might not be suitable as a pavement material as coarse aggregate. Thus a few laboratory tests were conducted after crushing them into fine aggregates to be used as a sub-base course. The results obtained are shown in Table-3 and the CBR value has been found to be more than that of the existing soil, which is about 8 in that region. Figure 2 and Figure 3 shows the results of the modified proctor test and direct shear test respectively conducted on the slate stone dust. The test results do not confirm the suitability of the material as a paving material and an exhaustive research needs be carried out before recommendations could be made for its use in road construction. Similarly, detailed studies need to be carried out to explore the possibilities of using it as a coarse aggregate.

Table 3. Laboratory test results conducted on slate stone dust

S.No.	Laboratory Test		Value
1	Liquid Limit (%)		28.50
2	Plastic limit (%)		21.57
3	Plasticity Index (%)		6.93
4	Finer than 0.075 mm (%)		70
5	Type of Soil		CL
6	Modified Proctor Test	OMC (%)	15.90
		MDD(g/cc)	1.582
7	CBR (%)		13.02
8	Direct Shear Test	c	0.055
		Φ (degree)	7.595

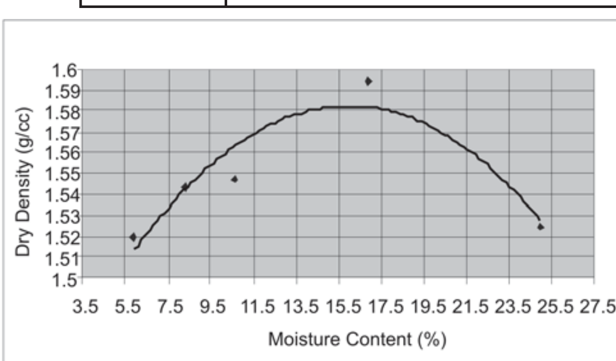

Figure 1. Modified Proctor Test on slate stone dust

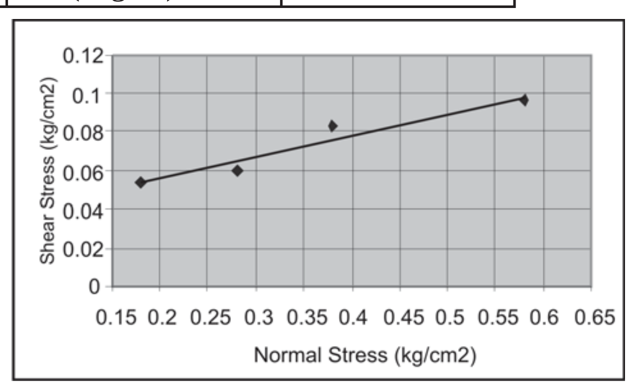

Figure 2. Direct Shear Test on slate stone dust

6.2 Test on recycled concrete aggregates (RCA)

RCAs are particularly very promising source of aggregates as 75 per cent of any typical concrete is made of aggregates. It results from crushing of waste concrete and may be used as a replacement for natural aggregates. Some of the problems associated with the use of RCAs as a pavement material are: lower specific gravity, higher water absorption, lower level of strengths and durability in concretes, impurities on the surface, lack of strong bond between cement paste and RCAs in concrete matrix. However, properties of RCAs can be improved by suitable organic or inorganic treatment systems. One of the options is to treat it with Nano-silica (NS) to improve its strength and other engineering characteristics. The NS used is usually in the form of stable dispersions of nanometer size silica particles and this dispersion is generally in water or other liquid medium. Particle sizes of NS range from 4 to 100 nano-meters in diameter with very high surface area of upto 750 m^2/gram of silica solids (note the surface area of Portland cement ranges from 0.25 to 0.40 m^2/gram). NS is available commercially now as an aqueous solution with a colloidal solid percentage of 30% (nano-particles of SiO_2 dispersed in water).

In the present study the RCAs were prepared by crushing (using jaw crusher) of concrete cubes made of M20 grade concrete and then sieving. Quantities of fine aggregates (size less than 4.75 mm) and coarse aggregates (20 mm size) obtained were 18 percent and 60 percent respectively. Raw RCAs (Table-4) were found to have specific gravity of 2.41, water absorption of 5.7 percent, Aggregate crushing value (ACV) of 30 percent and Los- Angeles Abrasion Loss of 30 percent.

Treatment of RCAs with aqueous dispersion of NS was done by soaking the specimens in the solution for 10 days. The Nano-silica treated Recycled Aggregates have a specific gravity of 2.62 with water absorption of 0.92 percent. These treated RCAs recorded an Aggregate Crushing Value (ACV) of 5 percent. Indian Road Congress specifies ACV to be less than 30 percent for cement concrete pavement and 45 percent for concrete used for other than wearing surfaces. The ACV indicates ability of aggregate to resist crushing and a lower figure indicates stronger aggregate with greater ability to resist crushing.

Table-4. Characteristice of RCA and RCA treated with nono-silica

Characteristics	RCA	RCA treated with Nano-silica
Specific Gravity	2.41	2.62
Water absorption	5.7%	0.92%
Aggregate crushing value	30%	5%
Los Angeles Abration Value	30%	5%

RCAs were used as coarse aggregates to prepare concrete cube specimens made from concrete with mix proportions (by weight) of: Cement: Coarse Aggregates: Sand: Water = 1:1.49:2.83:0.45.

A 10 percent NS dispersion was also added to the fresh concrete mix containing RCAs. Curing of concrete specimens was done conventionally by storing the specimens under water.

Cement hydration generates capillary voids of 10 to 1000 nm size and in a well hydrated paste with a low w/c ratio, the pore size would be less than 100 nm. Hence, NS with nano size dimensions can contribute effectively to the pore size refinement of the hydrated cement matrix.

NS solids could fill the voids between cement grains, resulting in immobilization of “free” water (“filler” effect) and thereby increasing the cohesivity of the fresh mix. Use of colloidal nano silica particles in aqueous medium aids better dispersion of nanoparticles in the concrete matrix and decreases agglomeration of nanoparticles which improves nanoparticles performance in concrete. NS enhances cohesiveness of mix besides reducing segregation and bleeding. Concrete made with untreated RCAs had a slump of about 15 mm with a compressive strength of 16 MPa. But, concrete made with NS treated RCAs had a slump of about 35 mm with a compressive strength of 22 MPa (Table-5).

Table 5. Slump and Compressive strength of RCA and RCA treated with nono-silica

Characteristics	RCA	RCA treated with Nano-silica
Slump	15mm	35mm
Compressive strength	16MPa	22Mpa

It was observed that NS treatment to the RCAs enhances many aggregate characteristic properties such as abrasion, aggregate crushing value and compressive strengths. This enhanced properties of RCAs lead to higher level of compressive strengths in concretes.

NS treatment to RCAs densifies the loose/weak mortar present on surfaces of RCAs. The reactive and filler nature of NS binds the densified surface mortar to the base stone aggregates. Well-dispersed nanoparticles act as centre of crystallization of cement hydrates, thereby accelerating hydration. However, real challenge is always to get an effective dispersion into NS solids into cement matrix.

7. CONCLUSION

Keeping in view the fact that construction of roads and highways has been given a priority by the government of India in the recent times, there is a huge demand for aggregates, which are becoming scarce and expensive. Thus there is an urgent need to investigate the possibilities of using locally available natural and waste materials for the construction of roads. Even though the government is trying to promote the use of such materials, the designers and field engineers are hesitant to use them due to several reasons and there is need to address this problem immediately. The first step in this direction would be to prepare a database, preferably on GIS platform with all details about engineering characteristics and economics of using them. The preliminary secondary survey on locally available materials shows that a number of unused materials are available in Rajasthan. Preliminary study has been carried out on slate stone dust, which is abundantly available in Nimrana block of Alwar district. Laboratory investigation results shows that slate stone dust material can be used as a material for pavement construction. CBR value of material and range of maximum dry density is quite sufficient for the subgrade preparation. It can also be used to enhance the properties of cohesion less soil and can be used for the shoulder preparation. However, detailed research needs to be carried out to examine the suitability of the material for different layers of a pavement structure. Also a preliminary study was carried out to improve the engineering properties of C&D materials by mixing with nano-silica with encouraging results. More studies need to taken-up to ascertain its suitability as a pavement material.

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LOW COST CONCRETE ROADS FOR VILLAGES

Prof. B.B. Pandey*

IIT Kharagpur has developed a new technology for the construction of roads with flexible concrete at a cost lower than that of a black top road. The expected life is about 15-20 years. With little maintenance The method of construction makes the concrete flexible, and the surface does not crack. It is labour based, maintenance free and ideally suited to rural road construction as per the new policy of the government where employment generation is very important for the empowerment of the poor. It requires less initial cost than the conventional pavement. The technology can also be used for overlays over damaged black top roads, pavements of footpath, roads of housing complex, container yards, haul roads near a mine, bus stops,parking area of light and heavy vehicles etc.

THE TECHNOLOGY

It consists of a formwork of recycled plastic in the form of a network of cells of size 150mmX150mm to 200mmx120mm and depth from 50mm to 100mm and placed over a compacted foundation. The foundation of the road is prepared as per standard specifications for road construction. A formwork of cells of polyethylene sheets is placed across the full width of road under tension (Figure 1) .Edge protection is provided by brick on end edge or concrete blocks.Shoulder protection up to 0.80mm on either side is necessary for preventing damage from edges. The cells can be filled with different types of concrete as described below.

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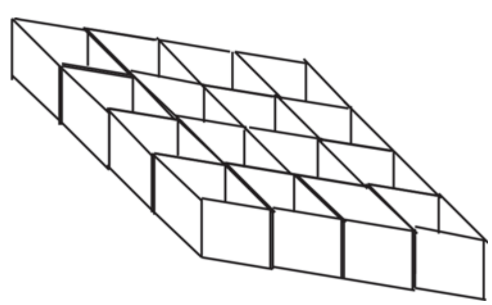

FIG 1 CELLS OF POLYETHYLENE SHEETS 150MMX150MM AND DEPTH VARYING FROM 50 MM TO 100 MM

There are three different ways in which pavements can be constructed.

Method 1

The formwork of cell is stretched under tension over a compacted foundation.A concrete 30 MPa strength with slump about 40 to 60mm is placed inside the cells.It is overfilled by 15 mm. The concrete is vibrated by surface vibrator. A little vibration is needed for compaction if the slump is about 50 to 60mm. Flakiness index of the aggregates were 38 and there was no problem in construction. Upon compaction, the thickness of

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pavement is about 90mm depending upon the overfilling. Commercially available super-plasticiser was used for reducing the water requirement in one of the projects at IIT Kharagpur. Curing of concrete by jute mats has to be done for about two weeks. Paddy straw and water hyacinth were successfully used in West Bengal. Banana leaves were used in Karnataka.The constructed part of the road was opened to light traffic such as bycycle, motorcycle,cycle riikshaw after two days. Laterite boulder was used in West Bengal for shoulder protection. Granular subbase with stone blocks at the edge of the cell filled concrete pavement was used iat Doddaballpur in Karnataka.

Method 2

The cells were filled with zero slump concrete with water-cement ratio of about o.30. The compaction was done with a road roller. In one of the projects, road roller was not available and the compaction of the zero slump concrete was done with a vibratory plate compactor.

Method 3

The cells were filled with single size 26.5mm aggregates and compacted by a road roller.A mortar of cement-sand were vibrated into the single size compacted aggregates filling up all the voids. Curing has to be done for two weeks.Since aggregates are already compacted by an eight to ten ton roller, light traffic can be allowed to move over the aggregates if there is any delay in grouting. Confined aggregates compacted by a roller is stable under traffic .

Performance of constructed pavements

(i) A pavement constructed in a village West Bengal in April 2004 is still in a good condition

(ii) Another 3.75m wide cell filled concrete pavement in a village in West Bengal attracted huge amount of quarry traffic after the construction. The formation width was only 5m against 7.5m s.There was no shoulder protection. The number of trucks weighing 50 tons were about 200 to 300 number per day carrying quarry sand from river bed.The subgrade CBR was about 3 percent. The half of the length of the pavement pavement ,as expected, failed within a year of construction after the monson.

(iii) A cell filled concrete pavement constructed at Doddaballapur about five years back is performing very well. A main village road carrying sand-laden vehicles had a good foundation of WBM along with a good subgrade and it is in sound condition

(iv) Accelearted load test at IIT Kharagpur by repeated application of a truck loaded to 20 tons indicated that even a 50mm cell filled concrete over a 150mm of soil-cement foundation would perform very well since concrete blocks cannot be pulverized by 0.80 MPa tyre pressure.

Why should such a pavement be adopted?

1 This technology creates a permanent road asset in villages. Even internal roads of lower width will have a long life .Brick soling being adopted in villages does not last even for three years.

2 It is labour intensive. Fabrication of formwork of cells generates about 300man days of work for a road 3.75m wide per kilometer of roads. Labour cost can be as much 40% as the total cost of roads fitting into the MNERAGA programme of the Ministry of Rural development

3 Use of machinery is minimal

4 Construction cost is less than any conventional one ,at best it can not exceed

5 The road is maintenance free

6 The concrete is flexible and conforms to the shape of the foundation in case of slight settlement unlike concrete pavements which cannot accommodate any settlement or drying shrinkage without cracking

7 Water from the subgrade/ subbase escapes to the atmosphere through fine gaps of 10 to 30 microns between the concrete blocks due to lower vapour pressure above the road surface keeping the foundation dry but at the same time the rain water does not enter through fine opening between the cast-in-situ blocks.

USE OF JUTE GEOTEXTILES IN RURAL ROAD CONSTRUCTION

Tapobrata Sanyal*

PRE-AMBLE

Geotextiles belong to a class of technical textiles that have varied applications in geotechnical engineering. The engineered fabric improves soil behaviour through processes of *separation, filtration, drainage and reinforcement.* Developed countries invariably use geotextiles made out of man-made fibres in road construction, for control of erosion, consolidation of soil and stabilization of slopes. In India we have the advantage of abundance of jute fibres supported by an industry that has century-old experience in making of any type of jute fabric.

JUTE GEOTEXTILES (JGT) & ITS TECHNOLOGY

Jute Geotextiles (JGT) is a natural variant of man-made geotextiles and used in the same way as its man-made counterpart the technology of which is accepted all over the world. Extensive studies and experiments have been conducted on JGT in technical institutions in India (e.g. IITs at Kharagpur, Delhi, Roorkee, Mumbai, Jadavpur University, Bengal Engg & Science University) and abroad (e.g. Singapore State University, Bangladesh University of Engg & Technology, Cranfield university, UK).

The purpose of using geotextiles in road construction is to strengthen the sub-grade for ensuring both longer life of the pavement and economy. Geotextiles—be it man-made or natural—acts as a separator between the sub-grade and the base course of the pavement overlying it, prevents migration of the top soil particles, helps dissipate development of overpressure by draining off water across and along its own plane. The aforesaid functions help consolidate the soil without extraneous mechanical intervention. Soil consolidation being a time-dependent process, the road sub-grade becomes self-reliant with the passage of time. Usual period of such consolidation, as observed in laboratory studies and field trials, is one to two years at the most, depending on the type of soil and nature & intensity of traffic.

In fact, all geotextiles act as change agents to the soil on which it is laid for a limited initial period of one to two years after which use of any geotextile is rendered redundant. JGT scores over man-made geotextiles due to its eco-concordance and price competitiveness, its excellent drapability (the best among all geotextiles), high secant modulus, initial strength and roughness co-efficient. It has been established after extensive field trials that improvement of CBR% of the sub-grade is minimum 1.5 times its control value. As soil consolidation is a protracted process, improvement in bearing capacity of soil may continue for several years. In some cases CBR value is seen to have increased even more than 3 times its control value after a lapse of 6 years. The higher CBR implies a lesser thickness of pavement. The cost of JGT is thus partially/fully compensated.

When mechanism of functioning of geotextiles as indicated is considered, bio- degradation of JGT is not a technically discouraging factor. Jute can be treated suitably with an eco-friendly additive to last for two to three years and thus help achieve the desired consolidation of the sub-grade. IIT Kharagpur has recently identified

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such an additive and has conducted durability studies on jute fabric in a research project assigned to the institute by National Jute Board under Jute Technology Mission launched by the Union Ministry of Textiles.

Jute Geotextile can add to the stability of road embankments also. Appropriately designed Jute Geotextile can be inserted within an embankment at different levels to control settlement and rotational slides. Additionally the embankment slopes that are vulnerable to erosion can be overlain by open weave Jute Geotextile to reduce the velocity of surface run-off after the rains and entrap the detached soil particles. Jute facilitates growth of vegetation. On bio-degradation of the fabric, vegetation can grow on the slope to control soil detachment. This is in fact a bio-engineering measure that is being increasingly favoured in the developed countries for controlling surface soil erosion with obvious environmental advantages. World Bank is supporting such measures.

CASE STUDIES WITH JGT IN ROADS

Jute Manufactures Development Council (JMDC), a national promotional body under the Ministry of Textiles, Government of India, (now **National Jute Board**) embarked

upon a Pilot Project under PMGSY with the support of Ministry of Rural Development/ National Rural Roads Development Agency and the Ministry of Textiles in December 2006. Central Road Research Institute (CRRI) was appointed as the Technical Consultant by JMDC. This project was spread over five states (Assam, Chhattisgarh, Madhya Pradesh, Orissa and West Bengal). Ten roads, two in each state, were decided to be constructed with JGT to study its effectiveness as separator, filter, drainage medium and reinforcing material. The main objectives of this Pilot Project were to evaluate the beneficial effects of the use of JGT in all its three major functions and standardize different types of JGT for different applications in road construction.

Table 1. Details of Ten Selected Roads for Pilot Project Using JGT

S.No.	State	Name of the Road	Length (km)
1	Orissa	Jadupur to Mahanangal, Kendrapara District	5.50
2	Orissa	MDR 14 to Chatumari, Jajpur District	4.00
3	Madhya Pradesh	Berasia to Semrakalan Approach Road, Bhopal District	5.10
4	Madhya Pradesh	Gehlawan village to PMGSY road, Raisen District	3.14
5	Chhattisgarh	Kodavabani to Khursi Road, Bilaspur District	4.80
6	Chhattisgarh	Kherajiti to Ghirghosa road, Kawardha District	5.50
7	West Bengal	Notuk to Dingal Road, West Midnapore District	4.80
8	West Bengal	Nandanpur to Marokhana High School Road, Hooghly District	6.20
9	Assam	Rampur Satra to Dumdumia, Nagaon District	4.20
10	Assam	UT Road to Jorabari, Darang District	4.60
	Total Length		**47.84**

Detailed Project Report (DPR) for each of these roads was prepared by CRRI. The project roads were constructed by the respective state agencies (State RRDAs, PWD). CRRI was entrusted with the job of quality management and third party random quality checking and performance evaluation. M/S STUP Consultants P Ltd, a reputed consultancy firm, was engaged as the Supervision Consultant by National Jute Board to ensure quality control over the works.

Ultimately out of the ten sub-projects, the one in Hooghly district of West Bengal (sl 8) could not be taken up due to unworkable site conditions. The road remains perennially water-logged. All the remaining nine roads have been completed. The road length in Jajpur district of Orissa however had to be reduced to 2.70 km (instead of 4 km) owing to land problems.

CRRI has completed the exercise on performance evaluation of five roads *viz*. 2 roads in Assam, 1 road each in Chhattisgarh, Madhya Pradesh and Orissa. CRRI monitored performance of the five roads for more than 18 months from the date of completion. It has also taken measurements (Benkelman beam deflection test, DCP test) on the five roads to evaluate performance of the pavements (sl nos 2, 4, 6, 9 & 10 in the table above). Though the final performance evaluation report has not been submitted by CRRI, the performance of all the five roads is satisfactory considering the comparative Benkelman Beam Deflection values (2009 and 2010). The range of deviations of deflections observed between 2009 and 2010 are as under.

ASSAM

- *Road in sl 10 (Darang district)*
  Range of Deviation of Deflection –(+) 0.15 mm & (-) 0.09 mm

- *Road in sl 9 (Nagaon district)*-
  Range of Deviation of Deflection—(-)0.42 mm to (-)1.86 mm

ORISSA

- *Road in sl 1 (Jajpur district)*
  Range of Deviation of Deflection –(+) 0.13 mm & (-) 0.08 mm

MADHYA PRADESH

- *Road in sl 4 (Raisen district)*
  Range of Deviation of Deflection –(-) 0.10 mm to (-) 0.91 mm

CHHATTISGARH

- *Road in sl 6 (Kawardha district)*
  Range of Deviation of Deflection –(+) 0.01 mm & (-) 0.46 mm

(N.B. (+) sign indicates reduction in deflection while (-) sign indicates the opposite.)

JGT samples were also exhumed and taken to the Institute of Jute Technology Kolkata for tests to observe the extent of degradation. It was observed that the tensile strength of the fabric got reduced by about 20% to 30% after 11 months and by about 70% to 90% after 23 months. Despite progressive de-gradation of JGT the pavement performed satisfactorily substantiating that JGT or any geotextile acts as a change agent to the soil (in the instant case, sub-grade) for a limited initial period by which time the soil progressively gains strength and ultimately becomes self-reliant as a result of development of effective stress within the sub-grade.

It has been observed in laboratory experiments conducted in Jadavpur University that the loss in strength of JGT is compensated by the gain in strength of the soil body. This means that the rates of the two contrasting phenomenon i.e. degradation of JGT and improvement of soil are in consonance. Sub-grade in a road draws its strength from separation and membrane effects principally. Pore-water pressure is relieved as a result of concurrent filtration and drainage functions by JGT. JGT was also used as a capillary cut-off in the Pilot Project to prevent ingress of water from below.

GIST OF OTHER SALIENT CASE STUDIES

JGT has been and is being applied in many roads—mostly low volume roads— for improvement of sub-grade with success all over the country. A synopsis of case studies in some roads constructed with JGT under varying climatic, geotechnical and loading conditions is presented below.

1. *Re-construction of a damaged road on soft marine soil at Kakinada Port, Andhra Pradesh* (case study by CRRI)

- *Objective* –Minimising post-construction settlement, lateral dispersion of fill by use of JGT
- *Soil composition*—Mainly clay up to a depth of 4m
- *Year of re-construction with JGT*-1996
- *Results*-
  a) After 7 months the shear strength of the sub-grade ensured the desired Factor of Safety.
  b) Water content, void ratio and compression index decreased while dry density and CBR value of the sub-grade increased substantially (nearly 3 times the control value after 7 years!
  c) The road is in excellent shape after more than 10 years after its re-construction.

2. *Internal road in Kandla Port, Gujarat* (case study by CRRI)

- *Objective*- Mitigation of the problem of settlement due to intermixing of sub-grade and sub-base in apportion of the road by use of JGT
- *Year of construction*-1997
- *Results*-
  a) Rut depth was minimized and other visual signs of distress were eliminated
  b) Settlement of the test section was compared to conventional pavement construction with increment of extraneous load from 0.5 MT/sqm to 2.0 MT/sqm @ 0.5 MT/sqm per month for a period of 3 months. Negligible settlement was observed with no visible signs of distress.

3. *Widening and strengthening of Munsirhat to Rajpur Road in West Bengal* (case study by Jadavpur University)

- *Objective*-Strengthening of the widened portion of the road with JGT
- *Soil*- Mostly inorganic clay mixed with silt. CBR value of the sub-grade was 3.5% on average. Plasticity Index -20.
- *Year of construction*-2000
- *Results*-

CBR value increased to 6.0%. from 3.5% No distress was noticed even after 6 years.

4. *Construction of Andulia –Boyratala Road in West Bengal* (case study by Bengal engineering & Science University, Sibpur)

- *Objective*-Strengthening the sub-grade and preventing interpenetration of sub-grade and sub-base by use of JGT
- *Soil*-Organic silty clay with occasional brown clay mixed with little sand. Soaked CBR value -3.16%
- *Year of construction*-2005
- *Results*-

Post-work evaluation carried out after 18 months showed that CBR value (unsoaked) rose to 10.47% on average with a high of 14% in one stretch.

5. *Stabilising road embankment in the approach to Hanuman Setu, Delhi* (case study by CRRI)

- *Objective*-Facilitating drainage from the embankment–fill by use of JGT
- *Soil*-Fly ash
- *Year of construction*-1997
- *Results*-

Migration of fly ash particles after the rains (100 mm rainfall) could be prevented due to effective drainage by JGT.

6. *Joshimath-Mallari road, Uttarakhand* (case study by CRRI)

- *Objective*-Prevention of subsidence and settlement of road by effective side drainage by using JGT-encapsulated road-side drains
- *Soil*-Slide-prone zone, consisting mostly debris
- *Year of construction*-1996
- *Results*-

Settlement was found to be in check after a year of construction of jute-encapsulated road-side drains.

Currently an international project on JGT for application in rural roads have been taken in hand with the financial support of the Common Fund For Commodities (CFC), Amsterdam, a unit of the United Nations, with the support of the Govts of India & Bangladesh. Field application numbering 16 in India and 10 in Bangladesh has commenced under this project out of which there will be 12 field applications in low volume roads(7 in India & 5 in Bangladesh). Performance will be evaluated by BESU, Sibpur in India and BUET in Dhaka,Bangladesh.(visit web-site at www.jutegeotech.com for details on the project and various technical aspects of JGT).

In the just concluded annual session of the Indian Roads Congress 2011 at Lucknow, a state-of-the-art report on applications of JGT prepared jointly by CRRI & NJB was released. BIS standards on rural road and river bank erosion control applications are under print. Besides, the Indian Roads Congress has permitted the use of JGT in roads as an innovative engineering material provisionally.

AVAILABILITY & QUALITY ASSURANCE OF JGT

The composite mills in West Bengal are capable of manufacturing Jute Geotextiles meeting the specifications of end-users. These mills will assure availability of Jute Geotextiles.

There exist full-fledged testing facilities in the Institute of Jute Technology and Indian Jute Industries' Research Association at Kolkata. NJB offers its free services for design and quality assurance of Jute Geotextile ordered by end-users.

CONCLUSION

More than fifty field applications with JGT in roads in India have so far been undertaken with remarkable improvement in CBR value (measure of bearing capacity of soil) of the sub-grade. Extensive laboratory studies in engineering and research institutes of India and abroad have been and are being carried on JGT. Besides, JGT fits in with the current global trend to use such materials in constructions as would ensure reduction of carbon foot-print.

Despite its good performance receptivity of JGT and response from the end-using organizations leave much to be desired. Immediate focus should be to standardize JGT in different soil-related applications. We look forward to support of organizations like IRC, CRRI, NRRDA in this regard.

Jute products are a major foreign exchange earner and play an important role in the national economy. Jute provides sustenance to at least five million people of the country directly and indirectly. Jute industry is struggling for survival in view of the ingress of artificial polymeric materials in the sack-market. It is time to support JGT to the extent technically permissible in geotechnical applications for the sake of a cleaner environment and larger national interests.

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CONSTRUCTION OF RURAL ROAD WITH CATIONIC BITUMEN EMULSION BASED COLD MIX TECHNOLOGY

Dr. N.K.S. Pundhir*

ABSTRACT

The conventional road construction with hot bitumen degrades the environment and consumes higher energy. Central Road Research Institute, with the help of Border Roads Organisation and local PWDs, conducted field trials for construction of bituminous surfacings such as bituminous macadam (BM) as base course and mix seal surfacing (MSS) and premix carpet (PMC) as wearing courses using bitumen emulsion with easily available machineries-concrete mixer and hot mix plant in different climates. The periodical post-construction performance evaluation indicated that MSS and PMC with bitumen emulsion performed better than paving 60/70 grade bitumen. Construction with cold mix is economical by 20 % as against hot mix. Cationic emulsion based cold mix technology can be effective for laying different bituminous surfacings as labour intensive method for poverty alleviation due to elimination of heating requirement. The paper describes construction of rural roads with cold mixes and post construction performance of trial sections.

Keywords: Cationic bitumen emulsion, cold mix technology, stability, cold mix , carbon footprints, BM, MSS, PMC)

1. INTRODUCTION

The conventional road construction with hot mix results in emission of hydrocarbon and suspended particulate matter (SPM) due to heating of binder and aggregates at 150-160^{O}C. The construction by conventional methods is energy consuming and pollute environment. Recently, Hon' able Supreme Court of India had to take stringent decision to minimize the pollution by issuing the directives to close down hot mix plants in and around Delhi which are supposed to be the source of environment degradation. Cold mixes consume little energy and does not create environmental pollution. Emulsion based construction of bituminous surfacings of rural to medium volume roads can be effective for laying different bituminous surfacings as labour intensive method for poverty alleviation due to elimination of heating requirement. Bitumen emulsions base cold mix technologies are used world-wide for road construction due to several advantages, such as, elimination of heating of binder and aggregate while producing mixes, coating of damp aggregate, protection of environment and energy conservation. The considerations for creating job for road construction by this technology are well taken as Government of India's Scheme MREGA provides minimum 100 days guaranty for employment in a year in rural India, which will make the cold mix technology a viable option.

2. FIELD TRIAL LOCATIONS

The trial sections were laid on NH-44, NH-1A, Agra - Kolkata Road from Km. 228 – 230 in warm climate on New Secretariat Road Aizawl (Mizoram) in high rainfall area and Dantaur- Khajuwala Road (Rajasthan) in desert.

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3. EXPERIMENTAL WORK

3.1 Cold Mix Design: The design of emulsion mixes is considerably more complex because of the difficulty of duplicating field curing in emulsion mixes and ultimate stability. Cold mix design involves:

(i) Characterization of Aggregate

The aggregates (Delhi Quartzite) were tested for their properties as per IS : 2386 and the gradation for SDBC and BM was determined as per MoSTR&H Specification.

(ii) Cationic Bitumen emulsion

The cationic bitumen emulsion has positively charge on bitumen globules and thus forms a strong bond with siliceous type of aggregates, whose surface has partial negative charge. The different grade of emulsion are job specific, such as Rapid setting-RS-1 is for Tack Coating & RS-2 is for surface dressing , Medium Setting (M.S.) is for Premix carpet and Patch Repair and Slow Setting SS-1 is used for priming and SS-2 is for cold mix of BM, SDAC, BC, MSS, Slurry Seal. The properties of emulsion are given in Table 2.

(iii) Optimization of Premixing Water Content:

For the determination of optimum water content for premixing, the quantity of bitumen emulsion is first estimated using the following equation.

P = 0.05A+0.1B+0.5C, where, P = Quantity of bitumen emulsion, %;

A = Percent aggregate retained on 2.8 mm sieve, B = Percent aggregate retained on 90 micron sieve, C = Percent aggregate passing on 90 micron sieve

Different batches of aggregates - emulsion mixes were prepared keeping the emulsion quantity constant and varying the water content. The optimum water co ntent was determined at which maximum aggregates coating and maximum workability achieved. The normally the optimum water for MSS and BM is in the range of 2-3 % by weight of aggregates.

(ii) Marshall Specimens for MSS/BM with emulsion: 1100gm graded aggregates were first moist with optimum water uniformly. The 6 percent bitumen emulsion was then added to the wet aggregates and mixed for 2 minutes for uniform binder coating. The cold mix was kept at 40^{o}C for three hours. The cured cold mix was then transferred into the Marshall mould with a filter paper on base plate and compacted with 75 blows of Marshall hammer on both faces. Similarly, the Marshall specimens were prepared with optimum water content and other bitumen emulsion content of 7 and 8%. The Marshall specimens were extracted from the mould after 24 hours. Specimens were then cured in air oven at 40^{0}C for 72 hours. The cured Marshall specimens were subjected to different tests such as bulk density, stability and flow value in dry state at 25^{0}C. Different design parameters like voids content, voids filled by binder will be calculated.

Optimisation of Emulsion Content : Optimisation of emulsion was determined with the bulk density , air voids and stability of Marshall specimens. The optimum bitumen emulsion content for MSS was found 7% by weight of aggregates. The properties of the cold mixes are given in Table 3.

Table 1. Properties of Aggregates

Sl. No.	Characteristics	Value Obtained
1.	Specific gravity Coarse aggregate	2.60
2.	Specific gravity, stone dust	2.68
3.	Aggregate impact value, %	22
4.	Water absorption, %	0.8
5.	Stripping, %	5-10
6.	Unit Weight, kg/m^3	1439

Table 2. Properties of Cationic Bitumen Emulsions used in field trials

Properties of Bitumen Emulsion	Results obtained		
	RS-2	**MS**	**SS-2**
Residue on 600 micron IS sieve (% mass)	0.02	0.01	0.01
Viscosity by Saybolt Furol Viscometer, seconds At 25^{0}C At 50^{0}C	 —— 152	 —— 101.4	 33.0 ——
Coagulation of emulsion at low temperature	Nil	Nil	Nil
Storage stability after 24 hrs., %, max.	0.6	0.4	0.1
Particle charge	+ve	+ve	+ve
Stability to mixing with coarse aggregate, % coagulation	——	——	——
Coating ability and water resistance (a) Coating, dry aggregates Coating after spraying water (b) Coating, wet aggregates Coating after spraying water	 —— —— —— ——	 Good Fair Fair Fair	 —— —— —— ——
Stability to mixing cement, %coagulation	X	X	1.1
Miscibility with water (coagulation)	Nil	Nil	Nil
Test on residue : (a) Residue by evaporation, % (b) Penetration, d mm at 25^{0}C/100 gm/5 sec. (c) Ductility, 27^{0}C/cm.,	 67 90 75+	 66.1 96 100+	 61.7 110 100+
Solubility ,in Trichloroethylene, %	98.7	99.2	99.5

Table 3. Job Mix Formula of MSS with Bitumen Emulsion (SS)

S. No.	Properties	Bitumen emulsion Content,%		
		6.0	7.0	8.0
i	Bitumen residue, %	3.8	4.4	4.9
ii	Bulk density, gm/cc	2.26	2.27	2.25
iii	Voids, %	9.1	7.81	7.92
iv	Stability, kg. at 25^{0}C	480	560	530
v	Flow, mm	6	3.5	6.5

4. CONSTRUCTION OF ROAD WITH BITUMEN EMULSION

4.1 Constuction of Bituminous Macadam with Cationic Bitumen Emulsion

4.1.1 Preparation of Road Surface: The emulsion was checked for its quality by inserting bamboo into emulsion drum . The drums of emulsion were rolled for a distance of about 4-5 m. to and fro for four to five times to make the emulsion homogeneous before its use. The pavement surface was thoroughly cleaned of all dirt, dust and other loose materials. All the cracks were cleaned and filled with bitumen emulsion of slow setting (SS-2) grade by spraying the material @ 5 kg per 10m^2 area. The aggregate passing 2.8mm and retained on 180mm were spread over the tacky surface and compacted with 8-10 tones road roller for cracks of 3mm wide. Proper cleaning was carried out in dry road condition before applying tack coat.

4.1.2 Preparation of Cold Mix: The graded aggregates of BM after blending different size of aggregates were charged into HMP. Optimum water 3% by weight of aggregates was added on conveyor belt. The required quantity of bitumen emulsion of SS-2 grade (6% by wt. of aggregates) was then added into damp aggregate at ambient temperature and mixed for two minutes to prepare cold mix . The additional time of mixing was avoided as it causes decoating of binder from aggregates. The cold BM mix was discharge into dumper (Photo 1).

4.1.3 Application of Tack Coat: The tack coat with bitumen emulsion of RS-1/ MS grade was applied @ 3 kg for 10m^2 area by mean of perforated cans as per IRC specification. The holes of cans were cleaned with water whenever tack coating was discontinued to avoid choking of the holes with residual bitumen. The cold mix was spread when tack coat turned black from brown colour after 15-20 minutes. At this point all water of emulsion was dissociated from bitumen by coagulation and drained off leaving behind the residual bitumen on the road surface. The road surface was made wet or damp if found dry, before applying the tack coat with emulsion.

4.1.4 Transportation of Mix: The cold mix was then discharged in wheel barrow and transported to construction site for spreading cold mix on tacky road surface. Due care was exercised to avoid taking wheel barrows on newly laid surface.

4.1.5 Spreading and Compaction of Cold Bituminous Mix: The cold mix was laid over the tacky surface and spread uniformly by paver (Photo 2) in required thickness. The cold mix turns black from brown colour after some time when water of emulsion exudes after breaking of emulsion. The cold mix was aerated for about two hours and then rolled with 8-10 tones three-wheel roller to compact the cold mix to achieve BM layer. The rolling was done with the outside drive wheel covering equal parts of the pavement and shoulder. The wheels were kept wet with water during compaction. The rolling was also repeated after 2 hours.

Photo 1: Preparation of Cold Mix for BM

Photo 2: Finished BM on By-pass by Hot Mix Plant Aizawl

4.1.6 Traffic Control: The traffic was regulated and test section was left to open for traffic after 4 -5 hours. The traffic at some test sections could not be controlled after completion of laying and hence, it was allowed at slow speed as per IRC guideline.

4.2 CONSTUCTION OF PREMIX CARPET AND MIX SEAL SURFACING WITH CATIONIC BITUMEN EMULSION

(i) **Application of tack coat :** The tack coat with bitumen emulsion of RS-1 or RS-2 grade was applied @ 3 kg for 10m^2 area. The holes of spray can are about 3 mm dia. The road surface was made wet or damp by sprinkling water before applying the tack coat with emulsion, as the road surface was dry. The holes of can shall be cleaned by water after tack coating.

(ii) **Preparation of cold mix :** The different sizes of aggregates of 13mm , 10mm and stone dust for specified grading were charged into concrete mixer (Photo 3) and then followed by addition of optimum premixing water content @ 3 per cent by weight of aggregates to damp the aggregate surface. The required quantity of emulsion (SS-2) was then added for MSS and mixed uniformly for two minutes. The cold mix of chocolate colour was discharged from concrete mixer (Photo 4). The 13mm and 9.5 mm were used in 2: 1 ration for PMC and the 2 % optimum water was used in the mix. The emulsion of M.S grade @ 6.5 % by weight of aggregates was used for cold mix PMC.


Photo 1: Charging aggregates into mixer


Photo 2: Production of cold mix

(iii) **Preparation of Cold Mix with Hot Mix Plant with out Heating:** The aggregates of different sizes – 20mm, 10mm aggregate and stone dust were charged from aggregate feeder on conveyor belt of Hot Mix Plant. The optimum water content @ 3 per cent by weight of aggregate was added on conveyor belt to damp the aggregate surface (Photo 5). The different sizes of aggregates were then charged into the drum of HMP without heating facility. The 6 % quantity of emulsion (SS-2) by weight of aggregates was added from emulsion tank by pump and mixed uniformly. The prolonged mixing time was avoided as it causes decoating of binder from aggregates. The cold mix from Mix Plant was discharged to dumper to transport to site for laying (Photo 6).


Photo 5: Adding water in Aggregates


Photo 6: Discharge of Cold Mix

(iv) Laying of Surfacings: The cold mix was brought to laying site was laid over tack coated area when emulsion turned black and spread uniformly in required thickness of about 33 mm loose mix (Photo 7). The cold mix turned black from brown after some time when water of emulsion exudes after breaking of emulsion. The cold mix was aerated for about two hours and then compacted with 8-10 ton road roller(Photo 8). The compaction was done during drizzling and section still performed satisfactorily.

(v) Traffic control : The traffic was regulated and test section was left open for traffic after 4-5 hours. The traffic at some location could not be controlled after completion of laying and traffic was allowed at slow speed as per IRC guidelines.

Photo 7: Spreading cold mix

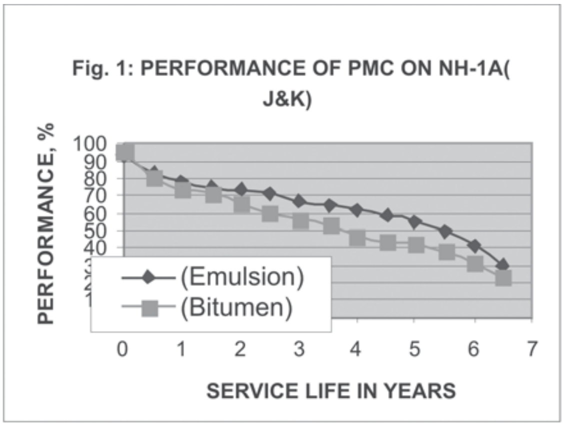
Photo 8: Compaction of cold mix

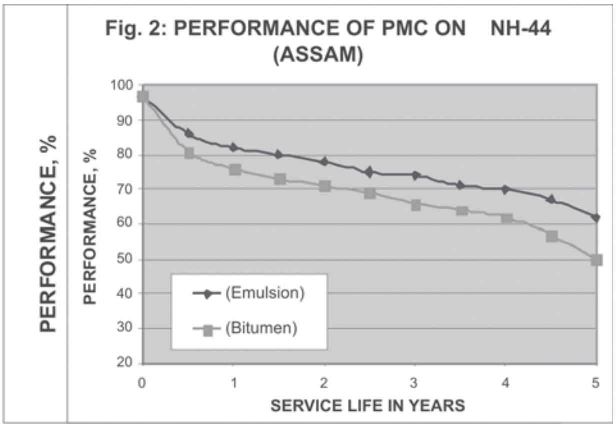
5.0 POST-CONSTRUCTION PERFORMANCE EVALUATION

5.1 Visual Condition Survey

The total distress appearing on pavement surface was categorized into eight different type – Appearance of binder, loss of aggregates, surface texture, cracking, pot holes, surface evenness, revelling and stripping.

The performance evaluation was carried out periodically each after six months. The joint report of each visual condition survey of test sections and reference section of mix seal surfacing (MSS) and premix carpet (PMC) for five and half years were prepared taking average of performance points. The plot of performance points v/s pavement service life in years for PMC test sections on NH- 1A (J&K) and NH- 44 (Assam) are given in figs 1 &2. and indicate better performance of test section with emulsion in comparison with reference sections –R with hot bitumen.





The performance of PMC and MSS in Aizawl was found satisfactory after one year (Photos 9&10)

Photo 9 : Good Performance of PMC after One Year in Aizawl

Photo 10 : Good Performance of MSS after One Year in Aizawl

6. COST ANALYSIS

The total amount of these materials required and cost of layer for the 50mm thick compacted BM mix is given in following Table 4.

Table 4. Cost Analysis of Cold Mix and Hot Mix Bituminous Macadam

Material for 50mm Thick BM	Amount required	Rate	Cost for cold mix layer (Rs.)	Cost for hot mix layer (Rs.)
20mm aggregate	207.5m³	28/cft	205151	205151
10mm aggregate	180m³	28/cft	177912	177912
Stone Dust	77.5m³	30/cft	82096	82096
Water	18200 lit.	0.20/lit	3640	-
Bitumen emulsion	40974 kg.	24/kg	983376	-
Bitumen	25025 kg	28/kg	-	700700
Anti-stripping Agent (1 % of bitumen)	250 kg	150 / kg		37500
Heating (LDO), 3%	154000 lit.	30/lit	-	462600
Transportation, Laying & compaction	514 MT	36/MT	18504	18504
Waste Bitumen (5%)	1251	28/kg		35035
Total			1470679	1719498
Cost per Sq. m.			210	246

Cost of road construction with bitumen emulsion is estimated to be cheaper by about 15 % in comparison with that of road construction with 80/100 bitumen.

7. CONCLUSIONS

- Cold mix technology is suitable for labour intensive as construction period during the year enhanced as construction is feasible in winter and rains.
- Construction of roads adopting specifications MSS, PMC and TCSD using bitumen emulsion is feasible in all weather including wet condition. Construction of roads for MSS and PMC with bitumen emulsion can be carried out by using concrete mixer as cold mix plant.
- 10 % Binder economy is achieved in MSS, PMC and TCSD due finely divided particles in emulsion
- TCSD with emulsion was found having better performance than PMC and MSS
- Reduction of cracks propagation to overlay when emulsion is used
- Performance of road with emulsion using MSS, PMC and TCSD was found satisfactory even after 5 years pavement service life

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LIME/CEMENT STABILISATION FOR SOIL AND GRANULAR MATERIALS

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1.0 INTRODUCTION

This paper suggest the criteria for improving the engineering properties of soils and granular materials used for pavement base courses, subbase courses, and subgrades by the use of additives/stabilisers, which are mixed into the soil/granular materials to effect the desired improvement. A number of additives are available to improve the physical and engineering properties of these materials; however, this document restricts itself to stabilisers such as lime, cement, flyash or a mixture of the above additives. The paper further prescribe the appropriate type or types of additive to be used with different soil types, procedures for determining a design treatment level for each type of additive, and recommended construction practices for incorporating the additive into the soil. These criteria are applicable to all type of roads having a stabilized pavement layer.

2.0 EFFECTIVENESS OF STABILIZATION

2.1 Pavement design is based on the premise that minimum specified structural strength will be achieved for each layer of material in the pavement system. Each layer must resist shearing, avoid excessive deflections that cause fatigue cracking within the layer or in overlying layers, and prevent excessive permanent deformation through densification. As the quality of a soil layer is increased, the ability of that layer to distribute the load over a greater area is generally increased so that a reduction in the required thickness of the pavement layers may be permitted. Some of the attributes of soil modification/stabilisation are indicated below.

a. *Quality improvement:* The most common improvements achieved through stabilization include better soil gradation, reduction of plasticity index or swelling potential, and increases in durability and strength. In wet weather, stabilization may also be used to provide a working platform for construction operations. These types of soil quality improvement are referred to as soil modification. Stabilisation can enhance the properties of road materials and give pavement layers the following attributes:

- A substantial proportion of their strength is retained when they become saturated with water.
- Surface deflections are reduced.
- Resistance to erosion is increased.
- Materials in the supporting layer cannot contaminate the stabilised layer.
- The elastic moduli of granular layers constructed above stabilised layer is increased.
- Lime stabilised material is suitable for used as capping layer or working platform when the in-situ material is excessively wet or weak and removal is not economical.

b. *Thickness reduction:* The strength and stiffness of a soil layer can be improved through the use of additives to permit a reduction in design thickness of the stabilized material compared with an unstabilized or unbound material.

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c. Possible problems: The increase in the strength of pavement layers is also associated with the following possible problems.

- Traffic, thermal and shrinkage cracks can cause stabilised layers to crack.
- Cracks can reflect through the surfacing and allow water to enter the pavement structure.
- If carbon dioxide has access to the material, the stabilisation reactions are reversible and the strength of the layers can decrease.
- The construction operations require more skills and control than for equivalent un-stabilized materials.

3. GENERAL GUIDELINES FOR SOIL/GRANULAR MATERIALS STABILISATION

3.1 Factors to be considered: In the selection of a stabilizer, the factors that must be considered are the type of soil to be stabilized, the purpose for which the stabilized layer will be used, the soil improvement desired, the required strength and durability of the stabilized layer, and the cost and environmental conditions. The following parameters are required to be considered while selecting the type of stabiliser.

a. Soil types and additives. There may be more than one candidate stabilizer applicable for one soil type, however, there are some general guidelines that make specific stabilizers more desirable based on soil granularity, plasticity, or texture. Portland cement for example is used with a variety of soil types; however, since it is imperative that the cement be mixed intimately with the fines fraction (< .075 mm), the more plastic materials should be avoided. Generally, well-graded granular materials that possess sufficient fines to produce a floating aggregate matrix (homogenous mixture) are best suited for portland cement stabilization. Lime will react with soils of medium to high plasticity to produce decreased plasticity, increased workability, reduced swell, and increased strength. Lime is used to stabilize a variety of materials including weak subgrade soils, transforming them into a “working table” or subbase; and with marginal granular base materials, i.e., clay-gravels, “dirty” gravels, to form a strong, high quality base course. Fly ash is a pozzolanic material, i.e. it reacts with lime and is therefore almost always used in combination with lime in soils that have little or no plastic fines. It has often been found desirable to use a small amount of Portland cement with lime and fly ash for added strength. This combination of lime cement- flyash (LCF) has been used successfully in sub-base course stabilization.

b. *General Guidelines*: The following are general guide lines when considering stabilization with different additives.

3.2 Lime Stabilisation

- Clayey soils including heavy clays, moorum and other soils met within alluvial planes can be effectively treated with lime. For effective stabilisation, a soil must have a fraction passing 425 micron sieve not less than 15 percent and Plasticity Index (PI) should be at least 10 percent.
- For effective stabilisation, it is desirable that the percentage retained on 425 micron sieve should be well graded with uniformity coefficient not less than 5. Besides clay mineral should belong to illitic, montmorillonitic or kaolinitic group.
- Organic matter in the soil selected for soil stabilisation should not be more than 2% and sulphate content should not exceed 0.2 percent.

- A pH value of 10 or 11 is desired for pozzolanic reaction to take place between clay minerals and lime for the formation of cementetious compounds.
- Soils having organic matter and soluble carbonate/sulphate contents in excess of 2.0% and 0.2% respectively require special studies.
- Some materials contain amorphous silica which although has low plasticity but reacts with lime to form the necessary cementation products and should thus be considered for stabilization with lime.
- Material containing high Kaolinite as the basic clay mineral usually have a fairly low PI with a high liquid limit and in such cases, lime should be considered for stabilization.

3.3 Cement Stabilisation

- Generally granular soils free of high concentration of organic matter or deleterious salts are suitable for cement stabilisation. For checking the suitability of soils, it would be advantageous to keep the following criterion in view.

  a) Plasticity Product (PP), expressed as product of PI of soil and percentage fraction passing 75 micron sieve should not exceed 60.

  b) Uniformity coefficient of soil should be greater than 5 and preferably greater than 10.

  c) Highly micaceous soils are not suitable for cement stabilisation

  d) Soils that are having organic content, higher than 2 percent and also those soils having sulphate and carbonate concentration greater than 0.2 percent are not suitable for cement stabilisation.

  e) Silty or fine sandy materials may exhibit a high liquid limit because of the high surface area of the particles. This material generally will not react with lime because of a lack of clay particles and can be stabilised with cement. However, cement stabilization with high doses of cement may tend to make cement stabilization uneconomical.

3.4 Lime-Fly Ash (LF) and Lime-Cement-Fly Ash (LCF) Stabilization

Stabilization of coarse-grained soils having little or no fines can often be accomplished by the use of LF or LCF combinations. Fly ash, also termed coal ash, is a mineral residual from the combustion of pulverized coal. It contains silicon and aluminum compounds that, when mixed with lime and water, forms a hardened cementitious mass capable of obtaining high compressive strengths. Lime and fly ash in combination can often be used successfully in stabilizing granular materials since the fly ash provides an agent, with which the lime can react. Thus LF or LCF stabilization is often appropriate for base and subbase course materials.

3.5 Desirable Properties of Lime, Cement and Fly ash for Stabilisation:

a. Lime: Lime is a broad term which is used to described calcium oxide (CaO) – Quick lime; calcium hydroxide Ca $(OH)_2$ - Slaked or hydrated lime and calcium carbonate $CaCO_3$ - carbonate of lime. The relation between these three types of lime can be represented by the following equations:

(1) $CaCO_3$ + heat = $CaO + CO_2$
(2) $CaO + H_2O$ = Ca $(OH)_2$ + heat
(3) Ca $(OH)_2$ + CO_2 = $CaCO_3 + H_2O$

The first reaction which is reversible does not occur much below 500^0C and is the basis for the manufacture of quicklime from chalk or limestone. Hydrated lime is produced as a result of the reaction of quicklime with water (equation 2). Quicklime (by the reversal of equation 1) and hydrated lime (by equation 3) will both revert to calcium carbonate is of no value for stabilization in civil engineering, although it is used in agriculture as a soil additive to adjust pH.

In dolomitic lime some of the calcium is substituted by magnesium. These types of limes can also be used for stabilization. Hydraulic lime also known as grey lime is produced from impure forms of calcium carbonate which also contain clay. They therefore contain less “available lime” to initiate effects on plasticity and strength. However, to compensate for this they contain reactive silicates and aluminates similar to those found in Portland cement. Thus whilst their immediate effect may be less than that of high calcium limes in the long term they may develop higher strengths. Generally use of dolomotic lime is not considered suitable.

Consequently in the context of this guidelines, lime stabilization refers to the addition of calcitic dry lime, commercially available, slaked at site, or pre-slaked lime delivered at site in suitable packing. Hydrated/ Slaked lime comes in the form of a fine dry powder.

Quicklime is available either in granular form or as a powder. It reacts violently with 32 % of its own weight of water ((equation 2) to produce considerable amounts of heat (approx 17 x 10^9 Joules per kg of quicklime are released).

Hydrated lime and quicklime are both usually added to soil in the solid form but they may also be mixed with water and added to the soil as slurry. The advantages and disadvantages of the three methods of application are summarized below.

- Dry hydrated lime
  a) Advantages: can be applied two to three times faster than slurry and is very effective in drying out soils.
  b) Disadvantages: produces a dust problem that makes it undesirable for use in urban areas, and the fast drying action of the lime requires an excess amount of water during hot, dry weather.
- Quicklime
  a) Advantages: More economical than hydrated lime as it contains approximately 25 % more available lime; Faster drying action than hydrated lime on wet soils;
  b) Disadvantages: field hydration less effective, producing a coarser material with poorer distribution in soil mass; quicklime requires more water than does hydrated lime for stabilization, which may present a problem in dry area and, greater vulnerability of site personnel to skin and eye burns.
- Slurry lime
  a) Advantages: dust free application is more desirable from an environmental standpoint; better distribution is achieved with the slurry; spreading and sprinkling operation are combined, thus reducing processing costs and, during hot & dry weather slurry application pre-wets the soil and minimizes drying action.
  b) Disadvantages: application rates are slower. High capacity pumps are required to achieve acceptable

application rates; extra equipment is required and cost is therefore higher; extra manipulation may be required for drying purposes during cool, wet, humid weather; not practical for use with very wet soils and if prepared from quicklime any benefits arising from the heat of hydration of quicklime are largely lost.

3.6 Purity of lime: The purity affects the strength of lime –soil stabilization. The effectiveness of lime in reaction with its clay minerals is dependent to a good extent on its chemical composition i.e. amount of calcium oxide present in the lime. The purity of lime is expressed as the percentage of calcium oxide present in the lime. It is generally recommended that the lime used for soil stabilization should have purity of 50 percent or above. The addition of lime should be correspondingly increased whenever the field tests show a lesser purity. Calcium oxide content in lime should be determined as specified in IS 1514-1990 "Indian standard method of sampling and test for quick lime and hydrated lime or IS 712-1984 "Indian standard specification for Building limes". Slaked lime supplied in airtight bags should not be stored for more than three months. Since lime deteriorates with storage the purity must be checked at site before use.

3.7 Fineness: For effective stabilisation with lime, uniform mixing is a pre-requisite and the degree of mixing depends on the fineness of lime. With fine lime, there will be a quick and effective reaction with clay minerals to form cementitious compounds. Lime for stabilisation shall conform to the fineness requirement of class C hydrated lime as specified in IS: 1514 or IS: 712, which is as under:

Table 1. Requirement of fineness for lime stabilisation

S.N	Sieve Size (Micron)	Percentage Passing
1	850	100
2	300	99 (Minimum)
3	212	95 (Minimum)

b. Cement: Cement for cement stabilisation should comply with the requirements of IS: 269, 455 or 1489.

c. Fly ash: Fly ash may be from anthracitic coal or lignitic coal. Fly ash to be used for the purpose of soil-lime-fly ash stabilisation should conform to the requirements given in table below.

Table 2. Chemical Requirements for Ash as a Pozzolana

Sl. No.	Characteristics	Requirements for fly ash		Method of test
		Anthracitic fly ash	Lignite fly ash	
1.	SiO_2 +Al_2O_{2+} Fe_2 O_3 in per cent by mass, Min	70	50	IS: 1727
2.	SiO_2 in per cent by mass, Min	35	25	IS: 1727
3	MgO in per cent by mass, Max	25	5.0	IS: 1727
4	SO_3 in per cent by mass, Max	2.75	3.5	IS: 1727
5	Available alkalies as Na_2O in per cent by mass, Max	1.5	1.5	IS: 4032
6	Total chlorides in per cent by mass, Max	0.05	0.05	IS: 1727
7	Loss on ignition in per cent by mass, Max	5.0	5.0	IS: 1727

Table 3. Physical Requirement for fly ash as a Pozzolona

Sl. No.	Characteristics	Requirements
1.	Fineness-specific surface in m^2 /kg by Blaine's permeability test, min	250
2.	Particles retained on 45 micron IS sieve, max	40
3.	Lime reactivity in N/mm^2 ,Min	3.5
4.	Soundness by autoclave test expansion of specimen in per cent Max	0.8
5.	Soundness by Lechatelier method-expansion in mm, Max	10

3.8 Selection of Stabiliser: The selection of the stabiliser is based on plasticity and particle size distribution of the material to be treated. The appropriate stabiliser can be selected according to the criterion shown in table 5. Some control over the grading can be achieved by limiting the coefficient of uniformity to a minimum value of 5; however, it should preferably be more than 10. The coefficient of uniformity is defined as the ratio of the sieve size through which 60 percent passes to the sieve size through which 10 percent passes. If the coefficient of uniformity lies below 5, the cost of stabilisation will be high and the maintenance of cracks in the finished road would be expensive. If the plasticity of soil is high there are usually sufficient clay minerals which can be readily stabilised with lime. Cement is more difficult to mix intimately with plastic material but this problem can be alleviated by pre-treating the soil with approximately 2 percent lime.

Table 4. Guide to the type of stabilisation likely to be effective

Type of stabilisation	Soil Properties					
	More than 25% passing the 0.075 mm sieve			***Less than 25% passing the 0.075mm sieve***		
	PI < 10	10 < PI < 20	PI > 20	PI < 6,PP < 60	PI < 10	PI > 10
Cement	Yes	Yes	*	Yes	Yes	Yes
Lime	-	Yes	Yes	No	*	Yes
Lime- Pozzolan	Yes	-	No	Yes	Yes	*

3.9 Two stage stabilization using lime followed by cement: Cement can be used to stabilize most of the soils. The principle exception are those that contain organic matter in a form which retards the hydration of cement and soils which are difficult to mix with cement on a account of their high clay content. In comparison with cement the potential use for lime in soil stabilisation is more restricted; used in equivalent amount it generally produces lower strengths than does cement and its main application is for use with clayey soils which are difficult to stabilize with cement. For these reasons the use of a two stage lime/cement stabilization process appears attractive as it offers the possibility of extending the range of soil which can be effectively stabilized. To achieve the maximum effect the lime and cement would not be blended but would be added separately. Lime would first be added to modify the properties of soil and this would be followed by the addition of cement to bring out a long term increase in strength.

3.10 Modification and cementation

There is a distinction between a stabilized soil "modified" for subgrade improvement and "cemented" (a cemented soil in this context can be one stabilized with lime as the clay-lime pozzolanic reaction products can be regarded as a cement) for use as a sub-base or base. The term “modification” and cementation are used in specifications to describe the degree and type of treatment.

The rapid action of lime on soil, which brings about a reduction in plasticity and a marginal increase in CBR is referred to as Modification. If conditions are favourable for the pozzolanic action to proceed, the lime stabilized soil will develop significant compressive and tensile strengths and it is then regarded as a “cemented” material.

If a very small quantity of cement is added to a soil, the properties may also be modified without much hardening or the development of significant compressive or tensile strength. In such cases the degree of cementation is relatively poor, but the properties of a material can nevertheless be considerably improved in this way. This treatment is also referred to as modification in the specifications generally considered.

When a material has developed sufficient tensile strength, it is regarded as a cemented material but there is no clearly defined boundary between modification and the division between the two is arbitrary. However it has been suggested (NAASRA 1986) that a 7 day unconfined compressive strength of 0.8 N/mm^2 could be set as the boundary between the two. Table 6 summarises the distinction between lime modification and cementation and the principal uses of both types of treatment.

Table 5. Suggested Application Of Stabilised Mixtures

Process	Purpose	Requirement
Modification sites	Improvement of access Rapid increase in bearing strength Improvement of workability and pulverization	 Large increase in plastic limit Large and rapid decrease in plasticity
Cementation(Stabilization)	Improvement of subgrade material Improvement of base material	Increase in bearing capacity and durability Decrease in plasticity Decrease in swell Increase in strength and bearing capacity CBR>80

4.0 SPECIFICATIONS AND TEST REQUIREMENTS FOR STABILIZED MATERIALS

4.1 General Requirement: The pavement performance of a stabilised road will be largely governed by the gradation and the type of soil/granular material used for the purpose of stabilisation. If possible the quality of material to be stabilised should meet the minimum standard set out in specifications. Stabilised layers constructed from these materials are likely to perform satisfactorily even if they are affected by carbonation during their construction time. Materials which do not comply with the requirements given in the specifications can be stabilised but more additive will be required and the risk from cracking and carbonation will increase. The strength of stabilized materials can be evaluated in many ways, of which the most popular are the Unconfined Compressive strength (UCS) test cement stabilized soil and the California Bearing Ratio (CBR) test for lime-stabilized soils.

4.2 Stabilisation with cement:

Requirement for Soil modification/Subgrade improvement: Cement stabilized materials can be used for soil modification or improvement of subgrade soil. It is recommended from economic consideration that mix in-place methods of construction be used for sub grade improvement and only granular materials & silty cohesive materials be used. (The assumption being that more clayey materials would be more effectively stabilized will lime). The main requirements for cement modification or stabilization of sub grade soil are summarized in Table 7:

Table 6. Soil Characteristics for cement modified soil/ improved subgrade/capping layer

Liquid Limit %	<45
Plastic Index	<20
Organic content	<2%
Total SO_4 content	0.2 %
Minimum Laboratory CBR @ 100% Proctor density or 95% Modified Proctor density	15
Min. cement content	2%
Degree of pulverisation	>60
Temperature for mixing	More than 10^0 C
Time for completing compaction	2 hrs

Requirement for bound sub bases/bases:

Granular materials, gravel, sand, lateritic soils, sandy silty material, crushed slag, crushed concrete, brick metal and kankar etc., stabilised with cement, lime-flyash-cement or lime-flyash etc., may be allowed for use as capping layer over weak subgrade, as sub-base and base layer of pavement. The main requirements of stabilised layers for different layers of a pavement structure as indicated above are summarized in Table 7 and table 8. However thickness of different stabilised layers, selection/choice for adoption of a particular grading and strength requirements of these layers are decided on the basis of pavement design and with specific approval of the engineer.

Table 7. Material Characteristics for cement modified granular materials

Liquid Limit %	<45
Plasticity Index	<20
Organic content	<2%
Total SO_4 content	0.2 %
Water absorption of coarse aggregates .	<2% (If the is value is >2% the soundness test shall be carried out on the materials delivered to site as per IS 383)
10% fine value in soaked condition when tested as per BS.812(III)	$\geq$50 kN

Table 8. Gradation requirement for cement bound materials for base/sub-bases/capping layer

Sieve size	I	II	III	IV
75.0		100		100
53.0mm	100	80-100	100	—
45.0	95-100			
37.5mm			—	95-100
26.5mm		55-90	70-100	55-75
22.4	60-80			
11.2	40-60			
9.5mm		35-65	50-80	
4.75mm	25-40	25-55	40-65	10-30
2.36mm	15-30	20-40	30-50	-
0.600µ		-	-	
0.425 µ	8-22	10-35	15-25	-
0.300µ		-		
0.075 µ	0-8	3-10	3-10	0-10
7 days Unconfined Compressive Strength(MPa) for cement bound materials or strength for lime, lime-flyash & lime-cement-flyash bound materials	12*/ 6**	7*/4.5**	3*/1.5*	1.5*/0.75** Or (CBR>15) 28 days

* Average value of a batch of 5 cubes

** Minimum strength of an individual cube within the batch. For Gr. IV the strength and CBR requirement are equally acceptable alternatives.

4.3 Stabilisation with Lime:

Requirement for Soil modification/ Subgrade improvement:

The properties of soil-lime mixes is usually assessed on the basis of strength tests made on the materials after the stabilizer has been allowed sufficient time to harden. The strength of stabilized soils can be evaluated in many ways of which the most popular is California bearing ratio (CBR) test for lime stabilized soils. Lime stabilization is generally recommended to improve the subgrade soils which are cohesive in nature. The lime is recommended because of its beneficial effects on plasticity, workability and strength gain. The main requirements for lime stabilized improved subgrade are summarized in the Table 8:

Table 9. Material Characteristics for lime/cement modified granular materials

Passing 75mm	100
26.5mm	95-100
75µ	15-100
PI	≥10
Organic content	< 2 %
Total SO4 content	< 0.2 %
Min. lime content	2.5 %
Degree of pulverization	>60 %
Min temp for mixing	100 C
CBR % at 100% Proctor density or 95% Modified Proctor density	≥15
UCS mpa	N.A
Time for completing compaction	3-4 hrs max.

The quality of lime shall be the same as given in section 2.2.

4.4 Stabilisation with lime fly ash (LF): Pulverised fuel ash (Pfa) or flyash has been recognized for many years as a valuable material for modifying and enhancing the properties of soils. Stabilisation of coarse grained soils having little or no fines can be accomplished by the use of LF or LCF Combination. Flyash also termed as coal ash is a mineral residual obtained from the combustion of the pulverized coal. It contains silicon and aluminium compound that when mixed with lime and water forms a hardened cementitious mass capable of obtaining high compressive strengths. Lime and flyash in combination can often be used successfully in stabilizing granular materials since the flyash provides an agent with which the lime can react. Thus LF or LCF Stabilisation in often appropriate for base and sub-base course materials. Flyash may be either from anthracitic coal or lignitic coal. Flyash to be used in Lime and flyash Stabilisation shall conform to the requirements given in Table 2 & 3. Lime shall conform to the requirement as given in section 2.

Design with Lime fly ash is somewhat different from stabilization with lime or cement. For a given combination of materials (aggregate, flyash and lime) a number of factors can be varied in the mix design process such as % age of lime-flyash, the moisture content and the ratio of lime-flyah. It is generally recognized that engineering characteristics such as strength and durability are directly related to the quality of the matrix material. The matrix material is that part, which consists of flyash, lime and passing 10 mm aggregates fines. Basically, higher strength and improved durability is achieved, when the matrix material is able to float the coarse aggregate particles. In effect, the fine size particles overfill the void spaces between the coarse aggregate particles. For each coarse aggregate material, there is a quantity of matrix required to effectively fill the available void spaces and to float the coarse aggregate particles. The quantity of matrix required for maximum dry density of the total mixture is referred to as the optimum fines content. In LF mixtures it is recommended that the quantity of matrix be approximately 2 percent above the optimum fines content. At the recommended fines content, the strength development is also influenced by the ratio of lime to fly ash. Adjustment of the lime-fly ash ratio will yield different values of strength and durability properties.

(1) *Step 1:* The first step is to determine the optimum fines content that will give the maximum density. This is

done by conducting a series of moisture-density tests using different percentages of fly ash and determining the mix level that yields maximum density. The initial fly ash content should be about 10 percent based on dry weight of the mix. It is recommended that material larger than 20mm be removed and the test conducted on the minus 20 mm fraction. Tests are run at increasing increments of fly ash, e.g. 2 percent, up to a total of about 20 percent. Moisture density tests should be conducted following procedures indicated in IS 2720, Part -7&8. The design fly ash content is then selected at 2 percent above that yielding maximum density. An alternate method is to estimate optimum water content and conduct single point compaction tests at fly ash contents of 10-20 percent, make a plot of dry density versus fly ash content and determine the fly ash content that yields maximum density. The design fly ash content is 2 percent above this value. A moisture density test is then conducted to determine the optimum water content and maximum dry density.

Step2: Determine the ratio of lime to flyash that will yield highest strength and durability. Using the design flyash content and the optimum water content determine in step 1, prepare triplicate specimen at three different lime flyash ratio. Use LF ratios of 1:3, 1:4 and 1:5. If desired about 1% of Portland cement may be added at this time.

Step3: Conduct durability test as per ASTM D 559.

Compare the results of the unconfined compressive strength and durability tests with the requirements shown in tables 8. The lowest LF ratio content, i.e., ratio with the lowest lime content which meets the required unconfined compressive strength requirement and demonstrates the required durability, is the design LF content. The treated material must also meet frost susceptibility requirements as indicated in the appropriate pavement design manuals. If the mixture meet the durability requirements but not the strength requirements, it is considered to be a modified soil. If the results of the specimens tested do not meet both the strength and durability requirements, a different LF content may be selected or additional portland cement be used and steps 2 to 4 repeated to ascertain strength and durability requirements as per stipulated specifications.

Gradation Requirements: Gradation Requirements for LF or LCF Stabilisation for stabilized subase /bases should be as indicated in Table 8.

4.5 Stabilisation with Lime, Cement and Fly ash: Portland cement may also be used in combination with LF for improved strength and durability. If it is desired to incorporate cement into the mixture, the same procedures indicated for LF design should be followed except that, beginning at step 2, the cement shall be included. Generally, about 1 to 2 percent cement is used. Cement may be used in place of or in addition to lime, however, the total fines content should be maintained. Strength and durability tests must be conducted on samples at various LCF ratios to determine the combination that gives best results. Gradation Requirements for LF or LCF Stabilisation for stabilized sub-base /bases should be as indicated in Table 8.

4.6 Cement Stabilised Fly Ash: This work shall consist of laying and compacting a sub- base/base course of fly as treated with cement on prepared subgrade /sub-base, in accordance with requirements of the specifications. This technique can be adopted for improvement of poor subgrade also. Fly Ash to be used for cement fly ash stabilization shall conform to Table 2 and 3. Pond ash or bottom ash, which do not meet the requirements of table 2 and table 3 can also used for cement stabilization work. However, in all cases the cement stabilized flyash/ bottom ash/ pond ash mix should develop adequate strength. The objectives of the mix design procedures, is to provide a pavement material having the required proportions of flyash and cement to meet the following requirements.

1. Provide adequate strength and durability
2. Be easily placed and compacted
3. Be economical

Amount of cement less than 2 % is not generally amenable to proper mixing and hence not recommended. After deciding cement and fly ash content for trial mix moisture density relationship has to be determined in accordance with IS:2720 (Part-7/8). The unconfined compressive strength test is done on samples compacted at maximum dry density and optimum moisture content. The mix proportion should be designed to obtain minimum unconfined compressive strength of 17.5kg/cm^2 after 7 days moist curing in a humidity chamber for samples with a length to diameter ratio of 2:1. Curing may be carried out in the temperature range 30 to 38^{o}C. The design mix should not only indicate the proportions of fly ash and cement, but also mention quantity of water to be mixed and a specified compacted density that is required to satisfy specified strength.

Cement: Cement conforming to IS:269-1989 or IS:8112-1989 can be used. Portland pozzolona cement should not be used for stabilisation, when fly ash is used as an ingredient.

Water: Water used for mixing and curing for stabilised mixes shall be clean and free from injurious amounts oils, salt and acid etc. It shall meet the requirement as IS: 456-200. Portable water is generally considered to be acceptable for stabilisation works. The permissible limit for soild in water should be as given in table 10.

Table 10. permissible limit for solid in water for soil stabilisation

Soilds	Permissible , Maximum
Organic	200 mg/litre
Inorganic	3000 mg/litre
Sulphates (as SO_4)	400 mg/litre
Chloride (as Cl)	2000 mg/litre
Suspended matter	2000 mg/litre

4.7 Test requirements:

4.7.1 The unconfined compressive strength test: This test is carried out on cylindrical or cubic specimens prepared by mixing the soil at a pre determined moisture content and stabilizer content and compacting the mixed material into a mould at either a pre-determined density or at a given compactive effort. The choice of specimen size and shape depends on the grading of the soil; it is clearly desirable to keep as small as possible the ratio of the maximum particles size to the smallest dimension of the mould. The following sizes of specimen for different group of material are recommended:

Table 11. Suggested size of moulds for casting materials samples

Fine grained material	Cylindrical specimens 100 mm high and 50 mm diameter, or 150mm cubic specimens
Medium grained material	Cylindrical specimens 100 mm high and 50 mm diameter, or 150mm cubic specimens
Coarse-grained material	150mm cubic specimens

Results on identical materials from strength tests on cubic specimens are higher than those obtained from cylindrical specimens; and cylindrical specimens with a height/diameter ratio of 2:1; have lower strength than cylindrical specimens with a height/diameter ratio of 1:1. Allowance therefore has to be made for this when comparing results obtained with specimens of different shapes. For the relatively low strengths encountered in cement-stabilized soils the results on different sized test specimens may be multiplied by the correction factors given in table 12 to calculate the approximate equivalent strength of a 150 mm cube. However, there is no unique relation between the strengths of specimens of the two shapes as the ratio depends primarily on the level of strength of the material.

Table 12. Correction factors for various size and shape of test specimens

S.No.	Specimen Size	Correction factor
1	150 mm cube	1.00
2	100 mm cube	0.96
3	200 mm x 100 mm diameter cylinder	1.25
4	115.5 mm x 105 mm diameter cylinder	1.04
5	127 mm x 152 mm diameter cylinder	0.96

4.7.2 Durability of Stabilized Materials: In order to check the durability of the stabilized mix for sub-base/ base, the following two methods are recommended. Method 1 is recommended for moderate temperature and climatic conditions, whereas method 2 is recommended for those regions where there is large variation in temperature and climatic conditions. The decision regarding the adoption of a particular should be as directed by the Engineer.

Method 1: Prepare two identical set (containing 3 specimens each) of UCS specimen which are cured in a normal manner at constant moisture content for 7 days. At the end of 7 days period one set is immersed in water while the other continues to cure at constant moisture content. When both sets are 14 days old they are tested for UCS. The strength of the set immersed in water as a % age of the strength of set cured at constant moisture content is calculated. This index is a measure of the resistance to the effect of water on strength. It this value is lower than 80% it is considered that the stabilization content is low and its value should be increased.

Method 2: This test is done as per ASTM standard No. ASTM D 559-71. It is generally known as Wetting and Drying test for determining durability of stabilised soil mixes, which determines the weight losses, moisture changes and volume changes (swell and shrinkage) produced by repeated wetting and drying of hardened stabilized soil specimens. The other is a freezing and thawing test (D D559-71) which follows a similar procedure except that wetting and drying is replaced by cycles of freezing and thawing.

In the wetting and drying test the test specimens are subjected to 12 cycles of wetting and drying, consisting of immersion in water for 5 hours followed by drying at 160^0 F (71^0 C) for 42 hours. After each cycle the specimens are brushed in a standardized manner with a wire scratch brush (18-20 strokes the sides and 4 at each end). The loss in weight of the brushed specimens, after each cycle are determined. In a parallel test the volume and moisture changes of the specimens after each cycle are determined.

The freezing and thawing test is similar to the wetting and draying test but the test cycles consist of subjecting the specimens to freezing conditions at-100F (-23^0C) for 24 hours followed by thawing at 70^0F (21^0C)for 23 hours. The specimens are brushed, as in the wetting and drying test, after each thawing cycle. For climatic conditions prevailing in India, durability under wetting and drying would have to be taken into consideration and durability under freeze/thaw condition does not generally apply.

The principal criterion set by the PCA is that the loss in weight of the specimens after 12 cycles of both freezing and thawing and wetting and drying should not exceed certain limits, depending on soil type. Granular soils of low plasticity are permitted to lose up to 14 percent of their original mass and cohesive clay soils are permitted to lose only 7 percent of their original mass. The reason of the difference is that granular materials abrade more readily than more cohesive soils and the wire brushing removes some material in addition to that loosened by the alternate cycles of freezing and thawing and wetting and drying. However, some researchers have found that the above requirements are too stringent and has recommended the following values.

Base: < 20%;
Subbase: < 30%
Shoulder: < 30%

5.0 CONSTRUCTION OPERATIONS

5.1 Procedure of stabilisation: The construction of stabilized road pavement layers follows the same basic procedures whether the stabilizing agent is cement lime or other hydraulic binder. The procedures can be divided in to two main groups:

1. Mix-in-place stabilization
2. Plant-mix stabilization

5.2 Mix-in-place stabilization: The main advantage of the mix-in-place procedure is its relative simplicity and hence it is particularly suitable for work in remote areas where plant mixing could prove logistically difficult. Its disadvantages are obtaining efficient mixing i.e. good distribution of the stabilizer, constructing thicknesses of more than 200mm and of poor levels.

In this process the material is stabilized in situ which requires the stabilizing agent to be spread before or during the pulverization and mixing of the soil and stabilizer. This is generally carried out with a purpose made machine although for small scale work in remote areas agricultural machinery can be adapted for use. Stabilisation in situ generally involves the following operations:

Initial Preparation: This involves excavating down to the in-situ material to be stabilized or placing imported material on the formation. The material to be stabilized then has to be graded to approximately the required levels. After which it is usually necessary to plough to loosen the material, one or two passes is normally sufficient.

Spreading the Stabilizer: Spreading the stabilizing agent at the required dosage rate can be carried out manually or by machine. When manual methods are used bags of stabilizer are spotted at a set spacing broken open and the stabilizer raked across the surface as uniformly as possible. Where quicklime is being used particular precaution need to be taken to protect the operators, this is especially true when the stabilizer is being spread by manual method.

Lime has a much lower bulk density than cement and it is possible, therefore to achieve a more uniform distribution with lime when stabilizers are spread manually. The uniformity of the layer of stabilizer spread over the surface, before the mixing operation, determines the uniformity of the mixed material produced.

Mechanical spreaders automatically meter the required amount of stabilizer on to the surface of the soil. Their use results in a much more uniform spread of stabilizer over the surface than can be achieved by hand spreading. The equipment need to be calibrated before use to ensure that the correct rate of spread is achieved and subsequently checked at regular intervals to ensure that the rate of spread remains within specified tolerances.

Addition of Water: If it is necessary to add water to bring the moisture content to the required value this can either be done as part of the mixing operation or after the material has been prepared prior to the addition of the stabilizer. To ensure a thorough distribution of the added water it is preferable to add water as part of the mixing operation. Water added during the mixing process should be through a spray system such that it is added in a uniform manner over the required area and mixed uniformly to the required depth. Where the mixing plant does not enable water to be added or where it is not possible to add enough during mixing it should be added to the prepared material using a spray system that enables the amount to be controlled over the whole area. The material to be stabilized should then be mixed prior to the addition of the stabilizer to ensure the distribution of the water throughout the layer.

Mixing Soil, Water and Stabilizer: Robust mixing equipment of suitable powerlike for the layer being processed is best able to pulverize the soil and blend it with the stabilizer and water. The most efficient of the machines available carry out the operation in one pass, enabling the layer to be compacted quickly and minimizing the loss of density and strength caused by any delay in compaction. Multi pass machines are satisfactory, provided the length of pavement being processed is not excessive and each section of pavement can be processed within an acceptable time.

The plasticity of the material is overriding factor in the ability of mixing plant to mix the soil with stabilizer. A review of work showed that all plastic soil could be satisfactorily mixed with cement with the plant. For cohesive soils a factor of the plasticity index of the soil multiplied by the percentage of the fraction of the soil which was finer than 425μm in particle diameter may be used to suggest the values for the different types of mixing plant available, which are given table 13.

Table 13. Soil Plasticity Limits for Stabilisation using different type of Plant

Type of Plant*	Plasticity Index x Percentage of fraction finer than 425 μm	Normal maximum depth mm) (capable of being processed in one layer
Agricultural Disc harrows, Disc ploughs, rotavators	Less than 1000	120-150
Light duty rotavators (< 100 hp)	Less than 2000	150
Heavy duty rotavators (> 100 hp)	Less than 3500	200-300 (depending on soil and horsepower)

*Selection of the appropriate plant should be left to the decision of the Engineer-in-Charge.

Graders have been used to mix stabilized material but they are inefficient for pulverising cohesive soil and even with granular materials a large number of passes are needed before the quality of mixing is acceptable. For these reasons the use of grader for the purpose is not suggested, however, if the same is being used, the uniformity of the mixed should be ensured before compaction.

Compaction: Compaction is carried out in two stages:

a) An initial rolling and trimming which may be carried out followed by a final mixing pass of the rotovator.

b) Final compaction and levelling in the case of cement stabilized material, must be completed within two hours of mixing. Delay in lime stabilization are less critical and for soil modification there may even be benefits in completing the final mixing, levelling and compaction between one and seven days after the initial mixing. This allow time for the reactions between the lime and clay to take place and thus provide a more workable soil. However, for lime stabilization as distinct from modification, the aim should be to complete compaction within as short a time as possible. This is particular true in hotter climates where problems of evaporation and carbonation are more likely to occur.

Curing: Proper curing is very important for three reasons:

a) It ensure that sufficient water is retained in the layer so that the hydration reactions between the stabilizer, water and the soil can continue

b) It reduces shrinkage, and

c) It reduces the risk of carbonation from the top layer.

In temperate climate curing presents few problem. It is usually carried out by sealing the compacted surface to prevent of water during the curing period (usually seven days) during which time all construction traffic must be kept off the stabilized material. Before spraying is started the surface should be swept free of loose material and any damp areas should be free of standing water. The following methods of curing are suggested.

a) covering with an impermeable sheeting with joints overlapping at least 300 mm and set to prevent egress of water.

b) spraying with a bituminous sealing compound.

c) spraying with a resin based aluminous curing compound such as is used for concrete. This has particular application where it is desirable to reduce the increase in temperature immediately under the surface which would result from the use of a black (bituminous) seal.

In a hot dry climate the need for good curing is most important but the prevention of moisture loss is very difficult. If the surface is constant sprayed and kept damp day and night the moisture content in the main portion of the layer will remain stable but the operation is likely to leach stabilizer from the top portion of the layer. If the spraying operation is intermittent and the surface dries from time to time (a common occurrence if this method is used) the curing will be completely ineffective.

Spraying can be much more efficient curing system if a layer of sand 30mm to 40mm thick is first spread on top of the layer. In this case the number of spraying cycles per day can be very much less and there is a considerable saving in the amount of water used.

When the stabilized layer is to be covered by other pavement layers the construction of the upper sections will provide a very good curing seal but be taken to ensure that this work does not damage the top of the stabilized layer. During the period of time prior to the construction of the next layer some system of curing is required because this is the most critical period in terms of shrinkage in the layer.

Prime can also serve as a curing membrane but results have shown that a prime breaks down when it penetrates into the surface and completely loses any ability to seal it. A portion of any curing membrane must sit on the surface to achieve an effective seal If the top of the stabilized layer is sprayed lightly with water followed by an application of a viscous cutback bitumen, the loss of moisture is effectively reduced to zero. Similarly the top of the stabilized layer can be sprayed with an emulsion to achieve the same result. It is essential however that all traffic is kept off the curing membrane for several days at which time excess bitumen can be absorbed by sanding the surface.

5.3 Plant-mix stabilization

In this process the materials are separately batched and mixed at a mixing plant. They are then transported to the site where they are laid by a bituminous paver and compacted. The advantages of the process are the good control on proportioning the materials, multi-layer work is no problem and good compacted levels are readily obtainable. The disadvantages are that output is lower than in the mix in place process, cohesive materials cannot usually be mixed and, in the case of cement stabilization, the mixing plant has to be relatively close to the site so that mixing, laying and compaction can all be completed within the stipulated two-hour time limit. The process is not, therefore applicable to small-scale projects unless there is a mixing plant near at hand.

To ensure complete distribution of the relatively small quantities of stabilizer, mixing should be carried out in a forced action mixer and except for non-cohesive granular materials, free fall mixes of the type used for mixing concrete should not be used. If it is proposed to use a mixer other than one with a forced action preliminary trials should be made to ensure that satisfactory mixing is achieved.

Vehicles transporting the mixed material should be of sufficient number and capacity to meet both the output of the mixer and spreading and compaction operations. International standards and specifications, for plant mixed cement stabilized material require it to be spread by a bituminous paver and spreading by grader is not permitted. If graders are used for spreading much of the advantage of plant-mix stabilization is lost as it is difficult to control levels and thicknesses of construction.

5.4 Compaction: Whatever method is used for mixing the soil with water and stabilizer material, the methods used for compaction are the same. In the case of cement stabilized materials, once the cement has begun to harden, it is important that the matrix is not disturbed; hence the requirement that compaction must be completed within two hours of mixing. The compacted density of the stabilized layer is a measure of the effectiveness of compaction and hence of its strength. The degree of compaction to be achieved in the field can be specified in two ways. In an end product specification the density of the layer in the field is determined and compared with a specified target density. Provided that the measured field density is greater than or equal to this limit the compaction in the field is deemed to be satisfactory. The main disadvantages of an end product specification are that a large amount of site testing is required and many of the methods in use are time consuming. This means that the results of the tests may not be available in time to remedy any deficiencies in compaction.

7.0 LIMITATIONS ON THE USE OF STABILIZED MATERIALS

7.1 General: The two major problems that arise with the use of stabilized materials in road pavement layers are cracking and the long –term durability of the material. The extent to which the either of these is a problem is intimately related to the purpose of the stabilized layer in the road pavement as a whole and it is therefore difficult to divorce the two factors. However, in this Chapter the problems that can arise are discussed.

7.2 Cracking in stabilized layers: Many factors contribute to the cracking and crack –spacing of stabilized pavement layers. Some of them are listed below.

1. Tensile strength of the stabilized material;
2. Shrinkage characteristics;
3. Volume changes resulting from temperature or moisture variations;
4. The subgrade restraint;
5. Stiffness and creep of the stabilized material, and
6. External loadings such as those caused by traffic.

As in the case of compressive strength, the tensile strength of stabilized materials takes time to develop. On the other hand stabilized material in a road pavement layer will be subject to volume changes from at least one of the factors listed above as soon as it is compacted. Cracking in stabilized layers due to changes in temperature or moisture content cannot therefore be avoided and must be accepted as inevitable although steps can be taken to reduce the effect. Cracking may also occur as a result of fatigue failure due to trafficking and is an entirely separate phenomenon from the initial cracking due to environmental changes.

Cracks in stabilized layers used at capping and sub-base level are unlikely to cause significant problems but at base level the cracks may be reflected through the surfacing. The existence of cracks in a road surface may be assumed to indicate need for remedial action. The consequences of not doing so may range from no problems at all to loss of interlock or to eventual failure when the stabilized layer has been reduced to unconnected blocks. Cracks may also permit ingress of water leading to weathering of materials at crack faces, de-bonding between pavement layers, or deterioration of moisture-susceptible layers beneath the stabilized layer.

7.3 Primary cracking: Cracks appear in cement-stabilized materials as a result of shrinkage and temperature fluctuations. The initial crack pattern is dependent on the early strength of the material and the properties of the material used. Materials which have low strength criteria normally also contain a higher proportion of plastic fines. The stabilized materials with lower strength and with high proportion of plastic fines have frequent but narrow cracks. Whether or not these frequent but fine cracks prove to be a problem depends to a large extent on the mechanical interlock at the face of the cracks. If the interlock is good the material performs satisfactory and the cracks are sufficiently fine for them not to be reflected through the pavement layer above. However, the lower strengths of these stabilized materials mean that they are generally only suitable for use in the lower layers of the road where cracking is less of a problem anyway.

On the other hand stabilized materials with high strength criteria and which have little, if any , plastic fines have fewer but wide cracks. These cracks are often wide enough for them to be reflected through the surface. In order to restrain the propagation of lateral reflective cracks such materials therefore have to be covered with a greater thickness of construction material than would otherwise be required.

The temperature at which the material is laid also plays a part in the type of crack pattern that is produced. Layers placed in cooler weather tend to develop fewer and narrower cracks as there is less thermal shrinkage. The stabilized layer may subsequently be in compression, apart perhaps from prolonged cold spells, so that cracks remain closed with good load transfer. Fewer cracks develop when the temperature difference between day and night during construction is not large, as thermal warping is reduced.

Lime- stabilized materials are also subject to cracking for the same reasons. However, the effects are not so pronounced; if the cracks occur before unreacted lime in the layer has been used up, either in pozzolanic reactions or by carbonation, the continuing pozzolanic reaction of the lime can result in self- healing (autogenous healing) of the cracks.

Given that cracking is inevitable, the ideal condition is for materials to have low early strength which lead to numerous fine cracks but high long- term strengths which mean good mechanical interlock at the face of the cracks. As lime is slower to react than cement this is another reason for favouring lime provided it can achieve high long- term strengths.

Another possibility is to use secondary additives to modify the hardening action of the cement to reduce its early strength without affecting its long-term strength.

7.4 Traffic-associated cracks: Quite separately and much more importantly than the primary transverse cracks , cracks may appear in stabilized bases of inadequate strength or inadequate construction thickness in relation to the traffic and the sub grade strength. Such cracking takes the form of “map” cracking which, in extreme cases, causes the stabilized material to deteriorate into small slabs with poor load transfer. Once started deterioration is likely to continue until the stabilized base becomes little more effective than granular sub-base.

When extensive cracking has developed the combined action of free water and traffic often results in the “pumping” to the surface of fine material from the underlying pavement layers where it is deposited in the cracks. The fines discolour the surface along the cracks making them clearly visible.

Unlike the primary cracking the appearance of traffic-associated cracks is not inevitable. It should not occur if the road pavement has been properly designed to take account of the traffic likely to be encountered during the design life of the road.

7.5 Durability of stabilized materials: The failure of stabilized materials by disintegration into a loose mass is not common. It is most likely to be due to deficiency either in the amount of stabilizer, deficiency in the quality of the stabilizer, or deficient compaction or curing. These problems should not occur if a good standard of preliminary testing for suitability and of quality control are maintained.

It is reported that the most common type of failure of stabilized layers is the peeling-off of surface dressings from stabilized layers. This is usually due to failure of top of the layers itself rather than any of the shortcoming of the surface dressing. The surface of the layer tend to disintegrate under traffic, the most likely cause of which is considered to be as a result of overstressing of the surface layer during the compaction of the stabilized material at the time of construction. This induce a series of shallow shear planes in the surface layer and result in a sharp falling-off density of the material towards the upper surface. Overstressing is most prevalent with uniformly graded non-cohesive sands. It can be avoided if special care is taken with the compaction and if towed vibrating rollers are used.

A survey of known causes of lack of durability of stabilized layers confirmed that the most common problem was surface disintegration of the primed layer during construction and scabbing of the seal in service due to an inadequate bond with the stabilized material. These problems are a result of inadequate compaction and curing and are more likely to occur in hot, dry climates. Apart from the problem of surface disintegration, long-term durability may also be impaired by the effects of sulphates and by carbonation.

APPLICATION OF COIR GEOTEXTILES IN THE CONSTRUCTION OF ROADS ON AGRARIAN SOILS

U. S. Sarma* & Anita Das Ravindranath*

INTRODUCTION

The coir nettings (geotextiles) are made of coir fibres extracted from the fruit of coconut *(Cocos nucifera*). These are the strongest fibres in nature and are known to elongate up to 30% of their original length. The coir nettings can withstand long term water logging. The positive effect of application of coir nettings on the embankment of roads to stabilize the slope and establishment of vegetation has been reported widely in the literature.

The Coir Research Institute (CCRI) of Coir Board, Ministry of Micro, Small and Medium Enterprises (MSME), Govt. of India, has earlier undertaken a few collaborative studies with the Cochin University of Science and Technology (CUSAT), College of Engineering and Technology (CoET), Kerala and National Institute of Technology (NIT), Thiruchurapally to establish the uses of coir geotextiles for construction of rural unpaved and paved roads.

This paper reports the utilization of coir nettings as reinforcements of ground soils having California Bearing Ratio [CBR] of less than 2 to improve the bearing capacity. The nettings also enhance filtration, drainage of excess water during rainy season and the soft soil consolidates before the nettings are subjected to the process of natural biodegradation during the period of about 10 years. The paper discusses a few experiment-cum-demonstrations that have been carried out in different parts of India to establish the uses of coir nettings in this field. The CBR of the soft soil treated with coir nettings has been found to increase by 2-4 times while retarding the rutting of the roads. The dust generation is also reduced to the minimum as it prevents the soil fines from flying off. A layer of netting below the bituminous layer is found to stop reflective cracking of the paved roads.

LAB STUDIES

A study was carried out in collaboration with Cochin University of Science & Technology (CUSAT), Kochi, Kerala to examine the performance of unpaved roads constructed on silty soils using coir geotextile reinforcement through a number of model tests. The strength aspects of coir goetextile were studied by performing CBR tests and Plate Load tests. The reinforcement aspects of coir geotextile were studied through CBR tests on 4 different types of soils. The separator aspects of coir geotextiles were also studied by performing plate load model tests within a test tank. The tests were conducted by applying static loads on base course through a plate of 200mm diameter. The test was repeated by placing geotextile at the interface between soil and base course.

The results of the study indicated that CBR value of the soil reinforced with coir had improved. From the plate load test also, it was found that the settlement can be reduced with coir geotextile. The wheel load tests [Fig.1] simulated the field conditions in a better way to understand the behavior of the pavement. It was observed that there was a remarkable reduction in rut depth at all loads stages. It was also found that after attaining a stable position, the rut depth did not increase further.

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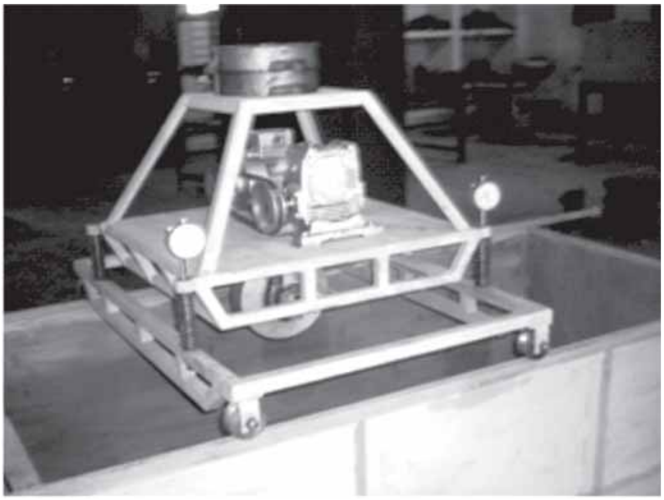

Fig.1. Wheel tracking apparatus

Initially, a rural road in a swampy area in Thanneermukkom village in Cherthala district of Kerala State in India was constructed by laying the coir netting over the sub grade. The methodology was adopted as described above. It has been found that even after 8 years, the low volume road is intact and has sustained heavy monsoon rains. Evidently, the rutting has not taken place due to efficient reinforcement, separation, filtration, and drainage properties of coir netting.

Based on the studies carried out at laboratory level and field level by the CCRI in collaboration with the institutes having expertise in the construction of roads in India, the Indian Roads Congress (IRC) has given accreditation to the use of coir geotextiles for use in the construction of roads for which the CCRI has been identified as a nodal institute.

It has mentioned that the coir geotextiles having mass per unit area of 400 to 900g/m^2 [Table 1] could be used which should meet the following specifications:-

Table 1. Specifications of Coir Geotextiles

Specifications	Machine Direction	Cross Machine Direction
Break Load, minimum for Dry coir	8-15 kN/m	3-8 kN/m
Break load, minimum for Wet coir	3-12.5 kN/m	2-5 kN/m
Trapezoidal tearing strength at 25mm gauge length, minimum	0.18-0.50 kN	0.15-0.35 kN

It specifies that the sub grade soil should have a California Bearing Ratio (CBR) of 2% [IRC 37-2001]. Where the CBR of the sub grade is less than 2%, a capping layer of 150mm thickness of material with a minimum CBR of 10% is required to be provided in addition to the sub base layer. The synthetic geotextiles have been used in highway constructions in many developing and developed countries but those are liable to pose environmental problems in the long run, therefore, there is interest in the use of coir geotextiles for such purposes which are not only eco-friendly but are good absorbents of water with minimum swelling and act as good reinforcement, separators and drainage materials.

In the light of accreditation of IRC, the National Rural Roads Development Agency (NRRDA) of Govt. of India has authorized the CCRI to use coir goetextiles in the construction of roads, in 9 states of the country, for a total length of 450kms in the first phase during the year 2011.

METHODOLOGY

Poor sub-grade soils pose a great challenge for construction of haul roads and other low volume roads. Coir netting can be successfully used for stabilizing poor sub-grade soils as these can reduce the substantial amount of aggregate required for stabilization just the same way as has been reported with the use of synthetic geotextiles.

Coir netting is spread directly over the roughly levelled poor sub-grade soil. In the case of clayey sub-grades it is recommended to spreading the fabric after placing a layer of sand of 10 mm to 20 mm thickness. The fabric is then surcharged with granular material preferably sand of 30 mm to 50 mm thickness to act as a lower sub-base and it is rolled initially with light rollers and later, if possible, with medium to heavy rollers. A layer of sub-base consisting of coarse aggregate or crushed rock varying in thickness from 200 mm to 300 mm may be placed over the sand layer and compacted. Under the surcharge action of sub-base layer and compaction rolling, the sub-grade loses water content through the filter fabric and gains strength. Unrolling of the netting can be done easily manually and great accuracy in alignment is not required. For multi-lane roads, an overlap of at least 300 mm is preferred where necessary. The fabric over the sub-grade may be spiked, if necessary, by the use of J-shaped wooden spikes driven at random as necessary to keep the netting in place during construction and rolling. Proper placement of netting to ensure lack of continuity with suitable over lapping is important. In the event of a tear occurring, the damage remains localized and does not spread progressively like in the case of a woven cotton fabric. In this respect, the coir netting can be considered to behave much like any other non-woven synthetic fabric. Any accidental damage does not therefore affect the overall performance of the coir netting. For unstable and wet sub-grades, coir netting provides a satisfactory solution to stability and drainage problems.

MATERIALS

Coir nettings/geotextiles are produced in ten specifications [H_2M_1-H_2M_{10}] as per the Bureau of Indian Standards, which vary in weight from 400 to 1400 g/meter and mesh sizes from 0.75 cm to 2.5 cm respectively. The Bureau of Indian Standards has published specifications for coir geotextiles. In this study H_2M6 (400 g/m^2) and H_2M5 (700 g/m^2) geotextiles have been used for application. [Fig.2]. The H_2M_6 and H_2M_5 are made up of Vycome coir yarn that is the typical low twist yarn made in a particular region [Vycome] in the state of Kerala, India for making mats and matting. Open weave coir netting is a woven fabric of two treadles weave in construction, made from coir yarn, in which the warp and weft strands are positioned at a distance to get a mesh (net) effect of 2.5 cm^2, 0.75 cm^2 and 1.27 cm^2. The open weave coir netting is manufactured in the following grades based on the mass:-

a) Grade I- 400g/m^2 (H_2M_6)

b) Grade II-700g/m^2 (H_2M_2, H_2M_5, and H_2M_8)

c) Grade-III 900g/m^2 (H_2M_9)

Fig. 2. H_2M_6, H_2M_5, and H_2M_9 Netting of coir

The Coir Board has established a testing laboratory for coir geotextiles at the Central Coir Research Institute, Alleppey, Kerala that is listed in the web site of ASTM [American Society for Testing and Materials] International Directory of Testing Laboratories. Rao and Dutta have discussed in details about testing of coir geotextiles.

The Tables 2 & 3 depicts the comparative properties of coir, jute and synthetic geotextiles. It can be seen that the coir nettings possess considerable strength to perform well under stress and strain due to its very high elongation and strength properties.

Table 2. The physical properties of coir fibre

ULTIMATE	
Length (mm)	00.60
Cell length/Diameter	35.00
SINGLE FIBRE	
Width (ì)	222
Length (mm)	150-200
Gravimetric fineness (tex)	40
Breaking load (kg)	0.45
Tenacity (gm/tex)	13.28
Breaking elongation	29.04%
Density (gm/cc)	1.40
Porosity	40%
Moisture Regain at 65% RH	10.5%
Swelling in water (dia)	5%
Rigidity modulus (dynes/cm^2)	1.89

Table 3. Comparison of properties of coir netting with other commonly used geotextiles

Tradenames	**Weight(gm/m2) ASTMD -1910-64**	**Thickness (mm) ASTMD -1777**	**Grab tensile Strength(N) ASTMD-1682**	**Elongationat break (%) ASTMD-1682**	**Trapezoidal tear strength N)ASTMD-(2263**	**Type**
Coir netting	400-900	6.5	700-1500	30	150-500	Woven
Jutefabric	680-750	1.75-1.85	800-900	15-20	300-350	Woven
Mirafi600X	–	–	1335	–	534	Woven
Terram(140)	280	1.1	1128	150	343	Non-Woven 75% Polypr. 25% Nylon

Field Studies

The construction of a village road namely, Kumbakkad – Chembakulam Road at Varkala Block in Trivandrum district is shown [Figure 3-5] using coir netting in position within the road structure. The netting acted as a separator to eliminate the punching of aggregate into the soft sub-grade as well as to resist the infiltration of fines from the sub-grade into the aggregate layer thus arresting any tendency for pumping. The drainage system also maintained optimum performance because the fabric did not get clogged under field conditions. The high tensile strength and tear resistance made the coir netting to act as a support membrane to reduce localized distress to the road surface by redistributing traffic loads over a wider area of sub-grade. This had of course resulted in the reduction of thickness of overall road structure resulting in some reduction in the quantity of earthwork as well. It has been reported that with the protection offered by geotextiles to the sub-grade, less sub-base is needed and indeed less sub-grade was needed to be excavated. A length of 100m was chosen on each of the roads as test stretches at each stretch. The stretch was further divided in to four sub stretches. The depth of placement of geotextile and the type of geotextile were varied in these different stretches.

The coir geotextiles placed in this location is H_2M_6. Laying of Geotextiles was done in August 2009 and construction of bitumen layer was done after one year. After that monitoring of settlement is noted continuously. No large settlement is noticed.

Fig.3. Before construction

Fig.4. During construction

Fig.5. After construction

In another study, carried out in collaboration with the NIT, Thiruchirapally, the Vellar Theru Road at Orthanadu Block in Thanjavur district has been constructed. This district is known for granary of Tamilnadu. The major agricultural crop is rice. The area of the district is 3397 sq.m. The geology of this district is sedimentary shown by lower cretaceous and gondwana formations. Depth of ground water level varies from 1 to 15 m. The average rainfall in Thanjavur district is 1288 mm. The project road passes through agricultural area. The link number of the Panchayat road is L049 and the given road length is 1.871 Km., the terrain is plain and the climate is hot and humid with rainfall more than 1000 mm. The road is used by 70 families directly and 30 families indirectly. The sub-grade soil details and traffic volume data are given in Table 2 and 3. The hourly variation of traffic and traffic composition are shown in Figures 5 and 6 respectively. The process of construction of the road is shown [Figure 6-8] from preparation of sub grade, laying of coir netting and finished road.

Fig.6. Finished subgrade

Fig.7.Laying of H_2M_6

Fig.8. Finished Road

CONCLUSIONS

From the field and laboratory experiments conducted on weak sub-grades with and without coir geotextile reinforcement, it has been established that reinforcement using coir-geotextile is economically advantageous compared to required thicker sections and/or chemical/mechanical stabilization techniques. Compared to existing methods of stabilization which have practical difficulties in the field, the application of coir geotextile is easier and more standardized.

The coir-geotextile reinforcement is a superior solution for the construction of low volume roads on weak sub-grades. Coir nettings have long life of at least 5 years. They have larger diameter, curvature and possess rigidity to bending. They are of higher toughness, strength, resistant to dampness, rot resistance, resilience, durability, and porosity, besides being hygroscopic, biodegradable, renewable, recyclable and versatile.

Bio-degradability is often considered a disadvantage of coir geotextiles. It is believed that after degradation the strengthening affect of the fabric is lost and the performance of the soil in terms of strength and permeability deteriorates. But coir has been found to be quite resistant to rapid deterioration when embedded permanently in wet soil below. In weak sub-grade consolidated under the overburden with consequent gain in strength with time, the performance of the structure becomes less and less dependent on the fabric. Therefore, long-term bio-degradability does not necessarily influence bearing capacity significantly. Coir degrades very slowly and produces lingo mass with extra nitrogen, phosphorous and potassium. Bio-degradation helps to minimize environmental pollution unlike synthetic fabrics.

ACKNOWLEDGEMENTS

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USE OF COLD MIX TECHNOLOGY FOR REHABILITATION OF RURAL ROADS

Rajib Basu Mallick*, A. Veeraragavan*

ABSTRACT

Rural roads generally consist of relatively thin bituminous surfacing over granular layers. In most cases such roads suffer from surface deterioration due to a variety or reasons, including traffic and moisture. Full depth reclamation (FDR) provides an environment friendly and cost effective procedure of rehabilitation of such roads, through in-place recycling of the bituminous and part of the granular layer. For effective use of the FDR process, proper consideration should be made regarding a few factors that have significant effect on the performance of the resultant base. These factors involve accurate determination of the depth of existing layers, selection of proper additives and curing periods. This paper discusses appropriate technologies that can be utilized for addressing these issues.

INTRODUCTION

There is a huge network of rural roads in India that needs to be maintained and rehabilitated properly at low cost. In most cases such roads are built with relatively thin bitumen mix (Hot Mix Asphalt, HMA) layer on top of granular base and subbase over subgrade. In many cases, these roads suffer from surface deterioration, because of the relatively thin HMA layer, moisture, and high loads from traffic, especially during harvest seasons. Because of economic concerns, it is not possible to afford a relatively thick HMA layer in such roads.

Full depth reclamation (FDR) is probably the most appropriate technology that can be utilized for rehabilitation of such rural roads in India. FDR is a cold recycling technique in which the entire existing bitumen pavement, along with part of the underlying unbound base material, is recycled in-place to produce a stabilized base course. The process results in a stabilized base course, which can survive with a relatively thin HMA layer. And, the process has many advantages – it is a cold process, requiring relatively less energy, an in-place process, therefore no transportation to/from plant is needed, and it utilize existing material, which means no or minimal amount of new materials are required.

On order to conduct a proper FDR, a pavement engineer needs to know the existing material/depth, utilize proper additive, if needed, conduct a proper mix design, be aware of the structural strength of layers made with the FDR material, and finally construct it with appropriate quality control.

OBJECTIVE

The objective of this paper is to present an overview of technology that can be used for the various critical phases of FDR such that a properly stabilized pavement with good performance can be obtained at a minimum cost.

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Description of FDR

In the FDR process (Figure 1) the existing bituminous mix material is mixed with a portion of the granular base material to create a recycled base course that is then overlaid with a new HMA surface layer (***1***). The recycled material can be mixed with emulsion or foamed bitumen/asphalt. Emulsion/foamed bitumen can be combined with cement or lime also. The performance related properties of the designed recycled base material are affected significantly by the proportion of bitumen recycled material and the unbound (granular) aggregate material. A FDR design, for example, might call for removal of 200 mm of existing material, with the assumption that the top 100 mm is bitumen mix and the lower 100 mm is unbound aggregate base. Accordingly, an optimum content of additive (emulsion or bitumen or cement) will be determined in the laboratory during the mix design process and recommended for the job. Since the properties, such as modulus and moisture sensitivity of the recycled base are highly sensitive to these proportions (100 mm of bitumen material/100 mm of granular base), any significant deviation from the assumed proportion in the field will affect the performance and the life of the reclaimed pavement significantly.

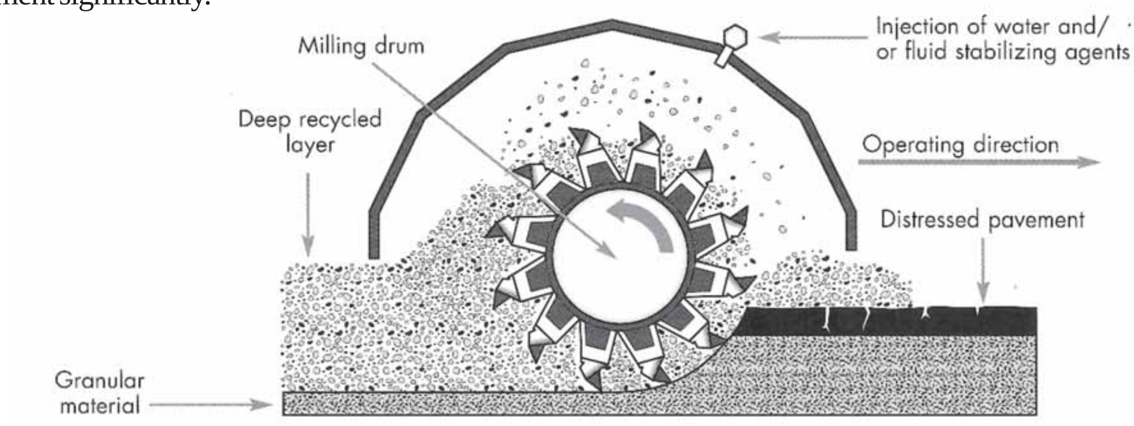


Figure 1. Full Depth Reclamation

Challenges in FDR

Some of the critical challenges that must be addressed properly for effective FDR are: 1. Determination of depth of layers in the existing pavement; 2. Structural design of FDR layer; 3. Mix design of FDR layer; 4. Selection of proper materials for FDR. The author has conducted extensive studies with different aspects of FDR on rural roads for Maine Department of Transportation (MDOT) and the Federal Highway Administration (FHWA) in the United States (US). Some of the technologies that have been used for addressing the above challenges in these projects are summarized below. Wherever applicable, specific details of the study are given.

Determination of depth

FDR is conducted with the existing bituminous mix layer and the underlying granular layer. The problem is that the actual in-place bituminous mix layer thickness can vary significantly from what has been assumed in the design. The design is generally based on plan data or data from a limited number of cores. Design data can deviate from the actual pavement thickness, and in typical few-mile long projects, cores are too sparse to capture the variability of the pavement structure throughout the project length. In the FDR process, the properties of the recycled base layer are significantly dependent on the structure and properties of the existing pavement. One potential scenario is that the actual bitumen thickness is generally greater than that assumed in the design. In this case, the recycled mix will have a deficiency of fine material. This fine material is critical for coating and forming the bonding matrix for stabilized recycled material, such as those reclaimed with foamed bitumen (***2***) and the deficiency will reduce the modulus of the stabilize recycled base. Similar problems occur if there is less than the assumed bitumen thickness, and there is an excess of granular material in the recycled mix (resulting in a lower than optimum binder content in the reclaimed mix). The literature is replete with cautions regarding the importance of pre-construction investigation and proper mix design as well as failures due to lack of knowledge of existing layers and materials (***3, 4, 5, 6, 7***).

A more accurate and comprehensive method for determining pavement structure variation in a way that can be incorporated into FDR design should be utilized. Ground penetrating radar (GPR) has been used to characterize the detailed variations in the pavement structure. This characterization serves as the basis for dividing the project pavement into homogenous sections. GPR works on the principles of radiating short electromagnetic pulses from an antenna and analyzing the amplitude and velocity of the reflected waves from pavement layers. The pavement thickness and density can be computed from these amplitudes and arrival times. The GPR data is collected at normal driving speed and is processed automatically to identify the significant pavement layers throughout the project length. Based on the data analysis, the project is divided into sub-segments with characteristic layer depths. The sub-segment analysis is used to identify core locations, and the cores are used to determine the pavement layer type in each sub-segment. An example showing the technology and application for six secondary roads in rural Maine, USA, is discussed below.

For a FDR project, prior to construction, GPR testing was carried out using a vehicle-mounted 1 GHz horn antenna GPR system. Data was collected at normal driving speeds, and passes were carried out in the wheelpaths and centerline of each lane in each direction (***8***). The data was analyzed to develop thickness profiles, as shown in Figure 2. The depths, as recorded by borings (locations are shown on Figure 2) are also shown. Table 1 shows the utility of the GPR data – segmentation of a project on the basis of correct pavement layer thickness, for mix design and construction. Table 2 compares the average and standard deviations of pavement depth obtained from both the GPR and the boring data. Note that while the average values are generally similar, both sources of data show high variability, a fact that suggests that the GPR (analyzed at every foot) is more able to capture the details of this variability. The results from GPR survey can be used to adjust the depth of reclamation in different segments of each project. Through this adjustment, the mix design of the recycled base material is optimized, and the life of the recycled pavement is increased. This improvement in the overall process has significant economic benefits.

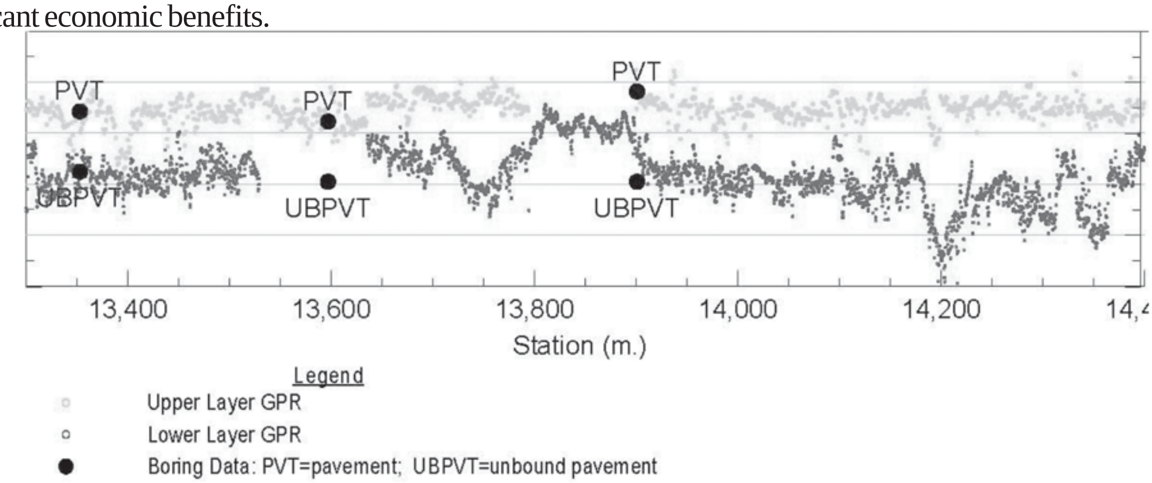


Figure 2. Sample of Processed GPR Data with Data from Borings

Table 1. Segmentation of Processed GPR Data from Borings

Station (ft, 0.3 m)		Milepoint (1.6 km)		Representative AC depth, mm
from	to	from	to	
0	1280	0.0	1.3	125
1280	2682	1.3	2.7	188
2682	3444	2.7	3.4	138
3444	5121	3.4	5.1	200
5121	5883	5.1	5.8	150
5883	6264	5.8	6.2	175
6264	6449	6.2	6.4	125

Table 2. Comparison of GPR and Boring Data for Pavement Depth, mm

Route	Location	GPR, mm		Borings, mm		
		Length (km)	Avg	Stdev	Avg	Stdev
7	Jackson-Dixmont	6.416	157.5	30.5	157.5	157.5
116	Chester-Lincoln	7.664	91.25	30.75	91.25	91.25
Conant Rod	Presque Isle	5.824	84.75	18.25	84.75	84.75
69, 139	Winterport	7.248	146	36.5	146	146
226	Chelsea-Randoplh	7.552	156.5	35	156.5	156.5
Jefferson St	Waldoboro	0.832	137.25	43.5	137.25	137.25

Structural design of FDR layer

Because FDR is an in-place recycling process, the structural strength (or stiffness) of FDR layers are highly dependent on the existing material and the construction process. During research conducted by the author, nondestructive tests were conducted at selected stretches of test sections on rural roads in Maine, USA, and analysis was carried out with layered elastic analysis method, backcalculation and mechanistic-empirical pavement design software (***9***). The results indicate that these pavements show non linear behavior and the moduli can range from 1 GPa to 6 GPa, with most of them showing 1.5 GPa to 3 GPa. Note that there is very high variability in the modulus values. The users are advised to build a database of typical modulus values from initial test sections, and also utilize in-place nondestructive testing (as opposed to laboratory testing of stiffness of field cores). This is because, field cores will be difficult to obtain without destroying them.

Mix design of FDR layer

Similar to HMA, FDR mixes must be designed properly to make them adequately resistant against stability and durability related distress conditions. A study was conducted by the author to develop a rational and practical mix design system for FDR (***10***). The results showed that by compacting samples with the Superpave gyratory compactor, an optimum total fluid content for FDR mixes can be determined by using the total fluid content versus dry density criteria (Figure 3). The dry density versus total fluid content curve indicates that the emulsion and the prewet water actually work together as a fluid, which affects the compaction procedure significantly. Figure 3 shows that the dry density peaks at 127.3 lb/ft^3 (2036.8 kg/m^3) at an optimum total fluid content of about 6 %. The peak of the resilient modulus at 1,000 Mpa is also very near to the optimum fluid content, at 6 %.

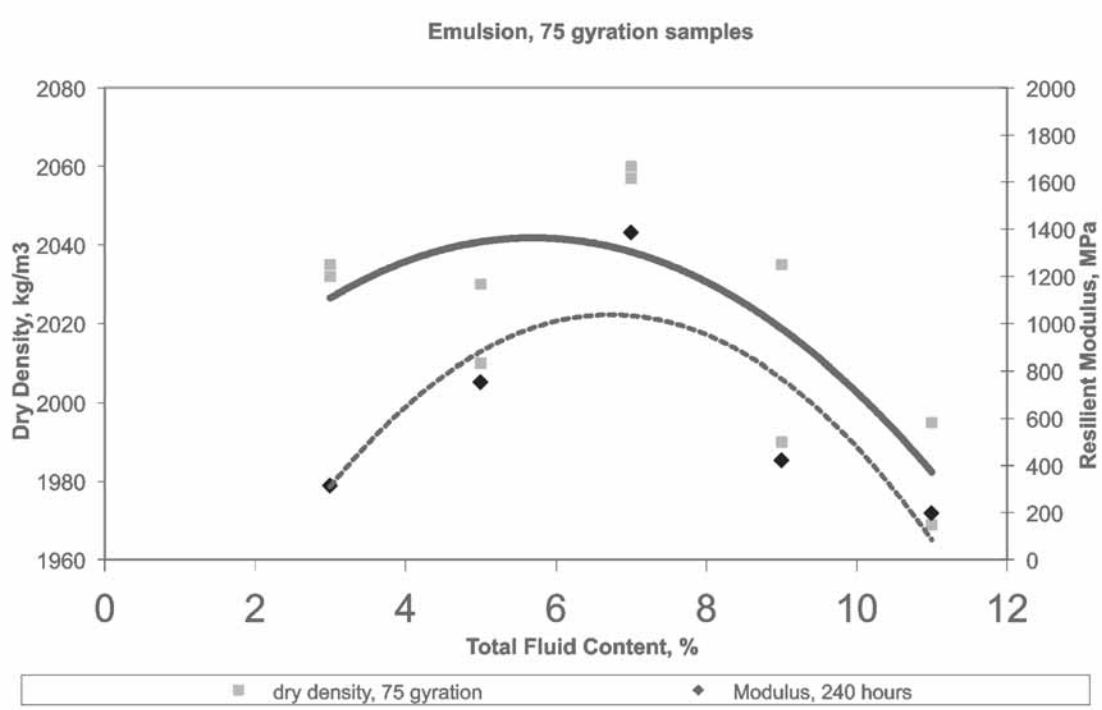


Figure 3. Plot of dry density and resilient modulus versus total fluid content (emulsion)

Curing Periods

In order to determine proper curing periods in the laboratory and in the field, moisture contents were determined for mixes and samples obtained at different times during construction. Figure 4 shows the moisture contents for three sets of samples for each test section – for samples taken behind the reclaimer after the application of the additive, for samples taken immediately before rolling, and for cores obtained at the end of curing (or the last set of cores taken for a specific test section). In all of the cases, except water section, the moisture content before rolling is higher than the moisture content at the end of application of additive. This is expected since according to current FDR practice in Maine, no precompaction curing was done. Therefore, in the laboratory, during mix design, it is suggested that no curing be done between mixing and compaction, to keep the moisture content of the samples at the time of compaction at least same as that at the end of mixing. Also, a curing period may be necessary to reduce the moisture content and facilitate compaction in the case of compaction in a Marshall mold. Since in this case compaction is recommended in a slotted gyratory mold (which allows squeezing out of water), and there seems to be no problem in achieving densification of mixes, no precompaction curing is recommended for design of FDR mixes. A review of the moisture content at the end of the curing period shows that all the moisture contents are between 2 and 3 %. The last set of cores for the sections other than the emulsion sections were taken before the end of the 7 day curing period. Taking this into consideration, the moisture content of all the mixes at the end of the 7 day curing period can be estimated to be less than 3 %. Therefore, maximum water content of 3 %, rather than a number of days, can be specified as criteria for curing in the field prior to placement of overlay. However, for practical purposes, a minimum of 10 curing days or a moisture content less than or equal to 3 % moisture content is recommended for field curing. Similarly, in the laboratory, post compaction curing should be continued until the samples have water content equal to or less than 3 %. If a number of days for curing, which can reduce the moisture content to 3 %, can be determined, then the samples can be cured for that many days, during mix design. During the initial mix deign conducted as part of this study, loss in moisture content was noted for the different mixes, through the 6 day curing periods. From the dry mass, the moisture content at different times was back-calculated. Figure 5 shows the moisture content of two different mixes, one with initial moisture content of 7 % and the other with initial moisture content of 10 %. In both cases it can be seen that the moisture content is reduced significantly less than 3 % within a day of curing at 40°C. Based on this observation, it seems to be justified to recommend that post-compaction curing be conducted in the laboratory for one day at 40°C. However, it should be noted that this is a general recommendation and may not be strictly valid for mixes with a wide range in material composition, particularly gradation, since finer mixes should take more time to cure than coarser mixes.

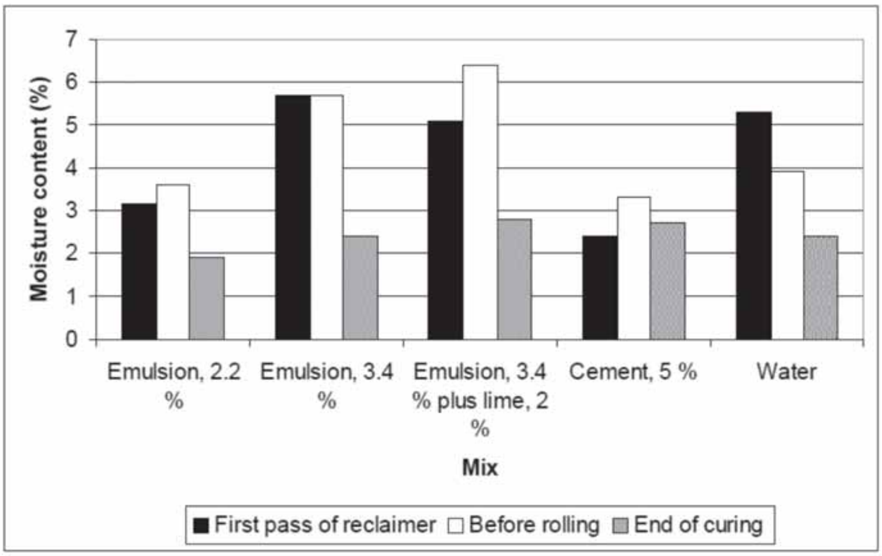


Figure 4. Moisture content of mixes

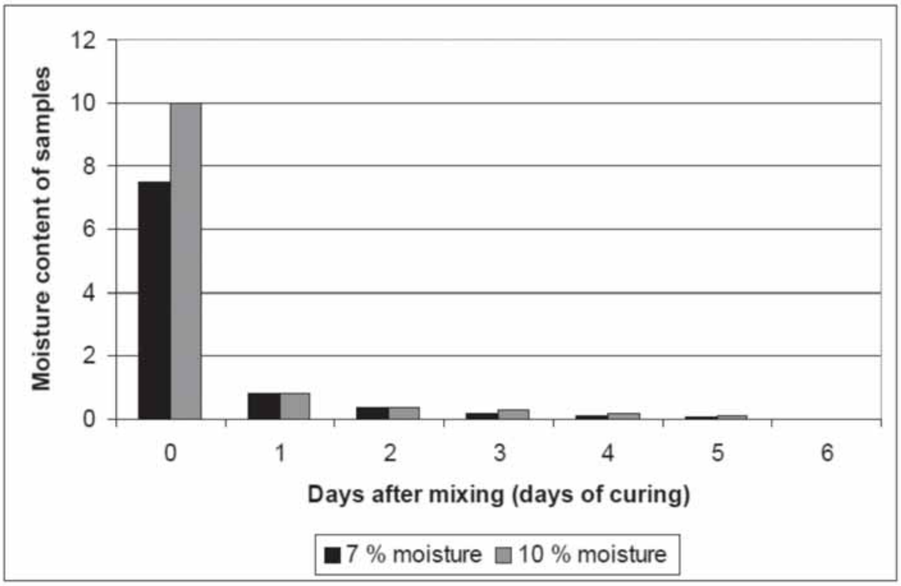


Figure 5. Moisture content of water mix samples from initial mix design

Performance evaluation - rutting and stripping potential of FDR mixes

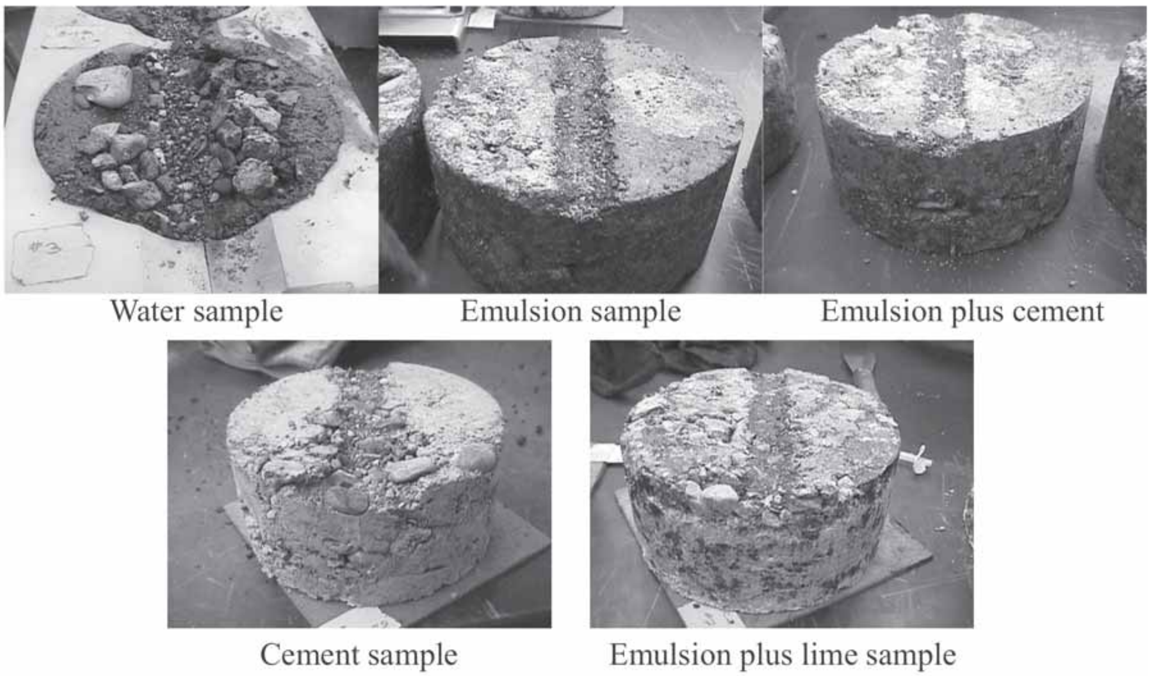
Rutting and moisture related stripping are the two main causes of failure in FDR layers. However, the use of a proper additive can be very effective in improving the resistance against these distress conditions in FDR mixes. To evaluate the effect of a few such additives, samples were compacted with mixes prepared with cement (5 %) plus 2 % premixed water (cement samples) and emulsion (3 %) plus lime (2 %) (emulsion plus lime samples), emulsion (3 %) plus cement (2 %) (emulsion plus cement samples) and emulsion (3 %) plus cement (2 %) and lime (2 %) (emulsion plus cement and lime samples). All of these samples, except the emulsion plus cement and lime samples, were then tested with the Asphalt Pavement Analyzer (APA).The testing was done by running loaded wheels under 690 kPa pressure over the samples. The entire testing was done under water. At the end of 8,000 cycles of loading, the rut depths of the samples were compared. A comparison of the final rut depth (at 8,000 cycles) (Figure 6) clearly shows the beneficial effect of additive in the mixes – the mixes with no additives, that is with water only, show the highest amount of rutting. In terms of the final rutting, the mixes can be ranked as (from best to worst) – emulsion plus cement, emulsion plus lime, cement, emulsion and water. A close observation showed that initially, with the start of loading, the bitumen and the bitumen rich fine particles on the surface began to strip off (commonly referred to as stripping) and then the bigger particles started raveling or pushing out, resulting in ruts (depressions). Hence, the initial stripping seems to have affected the rut depths significantly – higher the amount of stripping deeper is the rut. An examination of the tested samples showed that the slope of the plots, between 0 and 500 cycles can be used as indicators of final rut depths. The data clearly shows that the water samples show the highest slope of rutting versus cycles, indicating the highest degree of stripping.

APPLICABILITY OF FDR FOR RURAL ROADS IN INDIA

There are many important issues that need to be considered carefully for the successful application of FDR for rural roads in India. First, the thickness of the different layers have to be reviewed. It seems that in general, rural roads in India consists of 20 mm of bituminous layer over 150 mm of water bound macadam (WBM) – the thickness of the bituminous layer being much lower than what could be considered to be a minimum advisable thickness. However, this should not be of concern, since the basic idea is to combine whatever bituminous material is there, with sufficient amount of the underlying layer, to meet a specific gradation. The specific gradation could be of dense graded base course or that of a drainage base course layer. If the specific gradation cannot be achieved with existing materials, one can choose to spread desired aggregates on the existing pavement surface, ahead of the FDR equipment, and thereby include it in the final reclaimed mix.

The best approach is to take samples of the bituminous layer and the existing underlying layer, and mix the materials in different proportions, and determine the most suitable combination (that is, upto what depth the WBM layer should be reclaimed, and whether or not new materials are needed on the surface) in the laboratory, during mix design. This brings us to the question of compaction during mix design. Since, the material will contain relatively larger particles, one can consider the use of 150 mm Marshall mold instead of the 100 mm one. It will be better to determine the appropriate number of Marshall hammer blows that are required during mix design, by comparing field density with density obtained at different blows. For example, see the plots in Figure 7, which were developed for the determination of the appropriate number of gyrations for the use of Superpave gyratory compactor during mix design.

Guidelines for structural design of different types of rural roads (in terms of traffic) are given in Wirtgen reference manual (***11***, Wirtgen, 2004). The depth of recycling depends on the existing pavement structure as well as the additive that is to be used. There is also the option of reworking the existing granular material without the application of any additive, particularly when very little or no bituminous layer is available on the surface. Figure 8 (reproduced from ***11***) shows examples of two options. Note that the requirements of stiffness and strength for mix design are also given. For details on a variety of pavement structures/options of recycling the reader is requested to consult Reference ***11***.



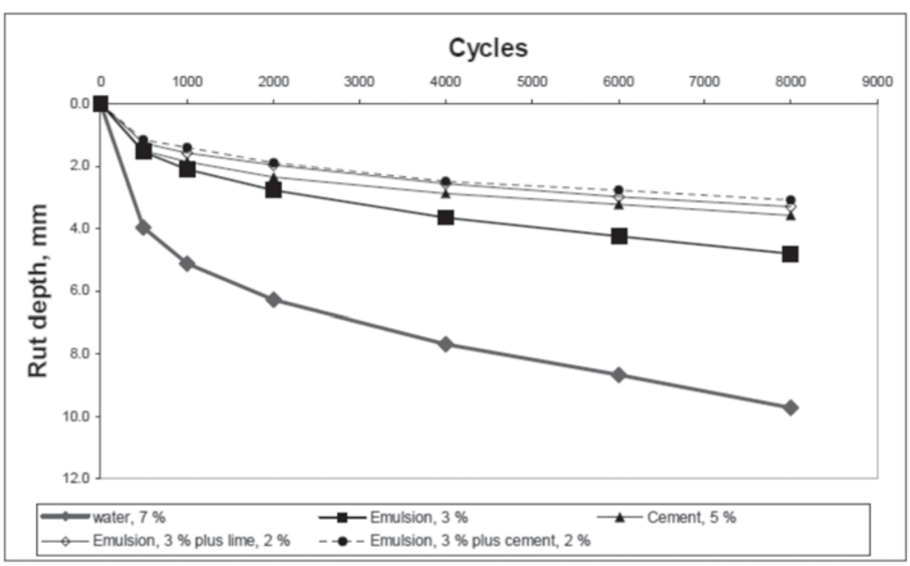


Figure 13. Plots of cycles versus rut depth

Figure 6. Results of APA testing

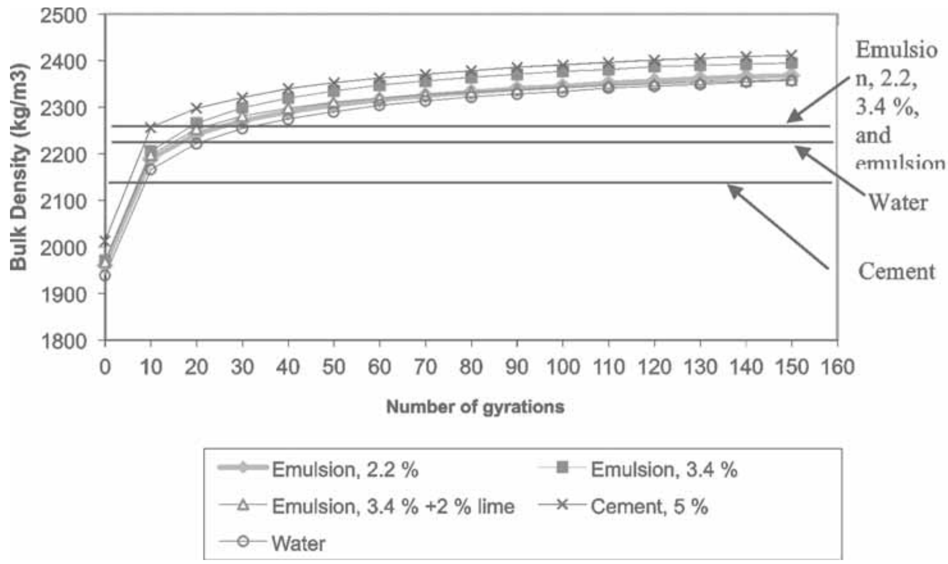


Figure 7. Density of laboratory compacted loose mixes and in-place density (indicated by horizontal lines)

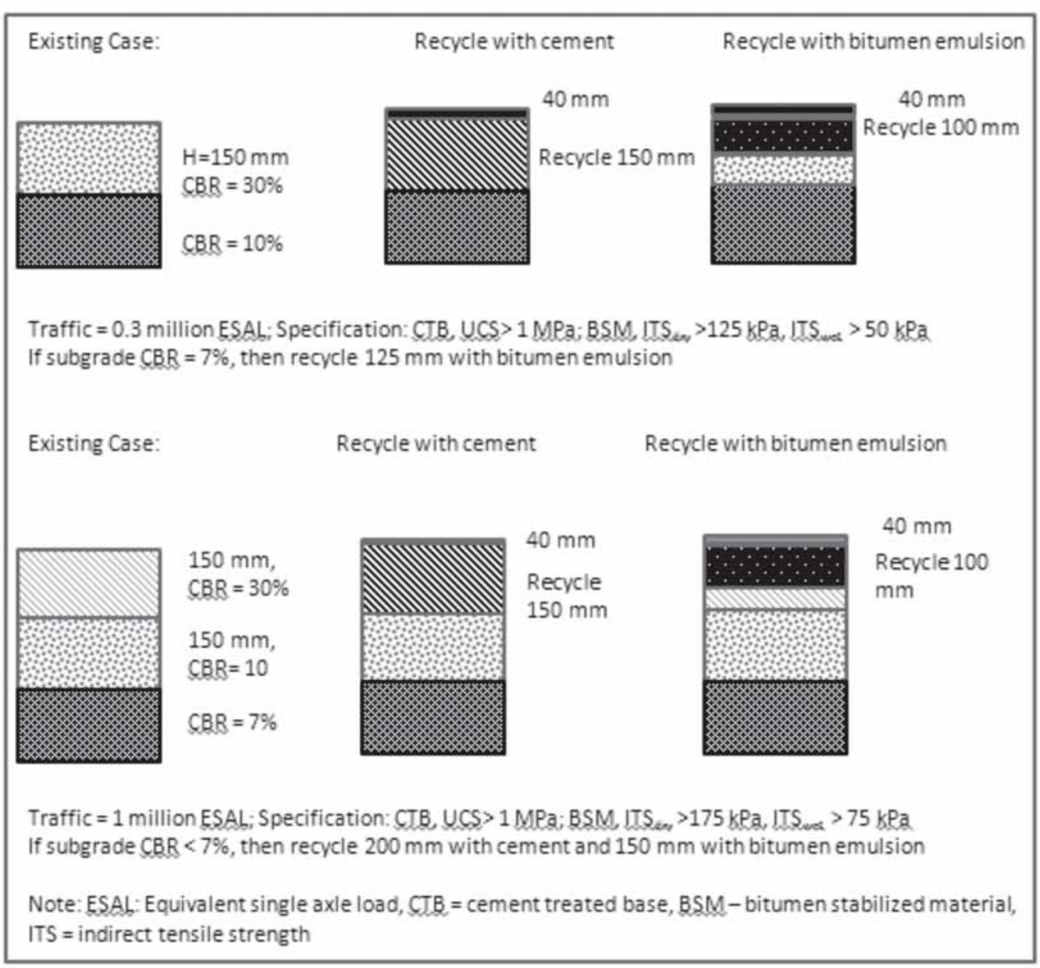


Figure 8. Examples of recycling options for different existing road conditions

Quality control procedures should include checking of thickness, amount of additives (emulsion, for example), and density. The road should be left to cure for sufficient period of time – under Indian conditions this time will be significantly lower. During this curing period, the movement of traffic should be controlled to proceed at slow speed, to prevent damage of the FDR base. If rain is anticipated right after FDR, then a fog seal can be applied to prevent ingress of moisture. Finally, the bituminous layer should be properly selected and laid down over the FDR base. Although this is not within the scope of this paper, the use of 20 mm "premix carpet" bituminous mix is strongly cautioned against. The thickness is not adequate to prevent the ingress of moisture inside a FDR base, and would definitely lead to its subsequent deterioration. Ideally, a layer of at least 40 mm thickness should be provided. While this could drive up initial cost, the road will definitely last longer, providing significant savings for users and the government.

CONCLUSIONS AND RECOMMENDATIONS

Based on a series of study and review of literature the following conclusions and recommendations can be made.

1. Full depth reclamation (FDR) is a very cost effective method for rehabilitating deteriorated pavements with relatively thin bitumen mix layer
2. FDR results in a stiff and durable base that would require a relatively thin HMA layer on the top – which can be economical for specifically rural roads
3. Knowledge of the depth of existing layers is very critical for obtaining good performing FDR pavements
4. Use of ground penetrating radar (GPR) can provide a very fast, nondestructive and reliable method of collecting depth data. The data can be used to segment projects on the basis of the variability in depth of different layers.
5. FDR can be conducted with water or emulsion or cement or preferably, with a combination of emulsion and cement/lime, as well as with foamed bitumen.
6. Maximum density and resilient modulus criteria can be used to select the optimum additive content for water and bitumen emulsion mixes.
7. Mixes with additives such as cement or lime develop strength faster and show significantly higher shear strength and stripping resistance compared to mixes with water only.
8. Marshall hammer can be used for compaction after determination of appropriate number of blows.
9. Several options are available for structural design/mix design and depth of reclamation, and the readers are requested to consult Reference ***11***.
10. Compaction in actual project must achieve at least 98 percent of the control strip density.
11. Increase in structural numbers for FDR layers should be considered for designing binder and surface layers

For a report on the detailed study on FDR, the readers are requested to download the documents from:

http://www.ltrc.lsu.edu/TRB_82/TRB2003-001955.pdf
http://www.rmrc.unh.edu/Research/past/P17/p17final.pdf

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USE OF MARGINAL MATERIALS & FLY ASH IN ROAD WORKS

U.K. Guru Vittal*

1. INTRODUCTION

In India, there are large deposits of marginal materials/ soft aggregates like moorum, laterite, kankar, etc., which are normally considered to be unsuitable for road construction. The general impression regarding the unsuitability of such aggregates for road construction may have arisen due to certain failures under heavy traffic condition, which have taken place in the past, due to their indiscriminate use in many cases. This has led to huge demand for good quality construction materials from the road construction sector. However, it is a well known fact that the naturally occurring good quality construction materials are fast depleting because of their over exploitation to meet the huge demand for construction of infrastructure projects. To cope with the huge demand of these materials at present and in the future, sufficient reserves have to be ensured and these reserves are non-replenishable. Besides, the amount of energy consumed for blasting hills for quarrying operations, crushing of rocks, transportation of this material to sites, mixing and laying, etc., is doing immense damage to the environment. While on the other hand, locally available marginal materials like moorum, laterite, gravel and industrial wastes like fly ash, metallic slags, etc, can be effectively used as such or after subjecting them to suitable treatment.

Presently the existing design methods for bituminous pavements of trunk roads are being revised to incorporate stabilisation techniques and bound materials. However more cost effective approach is needed for low volume roads to bring down their construction cost. In this regard, research work done abroad has brought into light increasing amount of evidence to show that more use can be made of locally available materials for construction of low traffic volume rural roads. Low volume roads typically carry less than 200 vehicles per day. Over a 20 year period, even with high growth rates, it is unlikely that the design traffic loading will exceed one million cumulative equivalent standard axles (msa). A very wide variety of non-standard materials have been successfully used where traffic is low, the environment understood and accounted for in the design and construction, quality control is adequate and maintenance interventions are timely.

2. MARGINAL MATERIALS USAGE

The Permanent International Association of Road Congresses has defined non-standard and non-traditional material as:

"....any material not wholly in accordance with the specifications in use in a country or region for normal road materials but which can be used successfully either in special conditions, made possible because of climatic characteristics or recent progress in road techniques or after having been subject to a particular treatment."

Specification criteria are generally based on easily measurable attributes of the materials, such as grading, plasticity and strength, although arguably these may not correlate well with the fundamental mechanical properties on which behaviour in service depends. Ideally specifications should be based on the results of carefully monitored performance studies and should incorporate any special design features that ensure their satisfactory performance. Standard

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specifications and guidelines for using granular materials, are usually drafted to enable the road to perform satisfactorily even under worse environmental and site conditions.

2.1 Usage in sub-base course

The sub-base course acts as secondary load spreading layer in flexible pavement and also as a drainage layer. To ensure drainage function efficiently, the amount of fines (material passing 0.075 mm sieve) must be limited. For well sealed roads in tropical areas, and where surface and road side drains are good, unsaturated moisture conditions prevail and sub-base specifications may be relaxed. The selection of sub-base material will therefore depend on the design function of the layer and the anticipated moisture regime, both in-service and during construction. In many circumstances the requirements of a sub-base are governed by its ability to support construction traffic without excessive deformation or ravelling. A high quality sub-base material is therefore required where loading or climatic conditions are severe. Otherwise, in case of low traffic volume roads, the material requirements for sub-base course can be relaxed.

2.2 Usage in road base

The road base is the main load spreading layer of the pavement. A wide range of materials can be used as unbound road bases including crushed quarried rock, gravels, etc. Alternatively, materials can be stabilised with cement, lime or bitumen. The suitability of materials for use depends primarily on the design traffic level and the local environment. Road bases are expected to conform to specified material gradation and provide high mechanical stability. The grading should contain sufficient low plasticity fines (material passing 425 micron sieve) to produce dense material, with less than 5 per cent air voids when compacted. CBR strength criterion of 80 per cent is preferred but in areas where rainfall is very low, 60 per cent CBR material can be used.

3. CLASSIFICATION OF MARGINAL MATERIALS

Marginal materials can be classified into five categories as given below:

Group I – Hard Rocks: Usually comprising materials that require crushing and processing but if the rocks are foliated, they may be classified as unsuitable for road works.

Group II – Weak Rocks: Material derived from weakly cemented, poorly consolidated or partially weathered parent deposits.

Group III – Natural Gravels: Transported and residual soils and gravels not meeting the minimum material standards for natural gravel road base.

Group IV – Duricrusts: Indurated or partially indurated soils not meeting the minimum material standards for natural gravel road base.

Group V – Manufactured materials: Include a wide range of man-made materials like industrial wastes, C&D waste, etc which can effectively be re-processed as granular pavement material.

4. PRESENT PROVISIONS FOR USE OF LOCALLY AVAILABLE MATERIALS

The Indian Roads Congress (IRC) / NRRDA guidelines advocate use of locally available materials. IRC SP:72, states that by maximising the use of locally available materials, suitable and economical designs can be worked out.

IRC SP:72 classify the locally available materials into following six categories:

(a) Selected granular soil for use in subgrade

(b) Soil stabilisation – Mechanical and using additives

(c) Naturally occurring softer aggregates like moorum, kankar, gravel, etc.

(d) Brick and over burnt brick metal

(e) Stone metal

(f) Industrial waste

The manner of using soft aggregates, as enunciated in IRC SP:72 are given in Table 1 below.

Table 1. Manner of using Soft Aggregates in Pavement Construction

Material Occurrence State	Manner of Using	Test/ Quality Requirement
In block or large discrete particles	As WBM without screenings/ filler in accordance with IRC:19, after breaking the material into required size	Wet AIV not to exceed 50, 40 or 30when used in sub-base, base and surfacing respectively
Graded form without appreciable amount of soil	As GSB layer or for base/ surfacing	PI < 6 for base/sub-base, PI between 4 to 10 for surfacing. Evaluated for strength by soaked CBR
As discrete particles mixed with appreciable amount of soil such as soil-gravel mixtures	Directly as soil-gravel mix for sub-base, base or surfacing	The material should be well graded and PI < 6 base/ sub-base, PI between 4 to 10 for surfacing. Evaluated for strength by soaked CBR

Further, while dealing with design of gravel/ soil-gravel roads, IRC SP:72 states that, 'minimum soaked CBR of 80 per cent for the gravel base material is often considered an additional requirement'. The gradation requirement for gravel base restricts percentage passing 425 micron sieve to 21 per cent and 75 micron sieve to 8 per cent.

5. OPTIONS FOR USE OR IMPROVEMENT

The use of granular material in pavement layers is best accommodated by the development of special design charts or guidelines that are appropriate for prevailing traffic and environmental conditions and afford flexibility for using marginal material. Many marginal materials are moisture sensitive and are not free draining, therefore it is often necessary to design the pavement and pavement layer configurations with the aim of preventing moisture ingress. To compensate for lower strength materials, greater thickness of material may be needed in some circumstances to protect the road from sub-grade deformation. Achieving even higher levels of compaction than those normally specified for sub-base and road bases, could be a relatively cheap method of increasing the stiffness of the pavement and increasing performance of certain marginal materials.

A review of marginal material usage worldwide showed that, in Australia CBR requirement for standard granular road base materials has been reduced from 80 per cent to 60 per cent when design traffic is less than 1 million standard axles (msa). Design charts for using CBR of 40 per cent have also been developed. In Kenya, relaxed road base requirements apply upto 0.7 msa. Road base materials in Kenya may have a reduced CBR of 50 percent with maximum PI of 15 in wet areas (annual rainfall more than 500 mm) and PI of 20 in dry areas. The maximum particle size is 40 mm and no aggregate particle strength requirements are stated. In case of Botswana, for roads carrying traffic upto 150 vehicles per day, relaxed specification limits for road base include minimum CBR of 45 per cent. In Bangladesh, crushed rock or brick with sand (CBR 60 per cent) is used as road base of low volume sealed roads. Similarly review of specifications in vogue in countries like Thailand, Brazil, U.K show that CBR requirement can be lower than 80 per cent for low traffic volume road bases and PI criteria needs to be fixed taking into account environmental and local site conditions.

6. USE OF FLY ASH IN ROAD WORKS

Central Road Research Institute, New Delhi has been working in the area of fly ash utilisation in road works since 1960s. Fly ash is considered as the world's fifth largest mineral resource. CRRI has been actively involved in R&D activities for utilisation of fly ash for construction of roads and embankments. Under the Fly Ash Mission, the task on 'Roads and Embankments' was implemented by CRRI. Several demonstration road projects involving use of fly ash have been undertaken by CRRI.

6.1 Use of fly ash for rural road construction

- Use of fly ash has been recommended to replace a part of cement in roller compacted concrete and also in pavement quality cement concrete (upto 35 per cent of cement can be replaced as per IS:456)
- Fly ash can be used to replace upto 50 per cent of sand in base course construction using lean cement fly ash concrete/ dry lean cement concrete (DLC).
- Fly ash admixed concrete can be used for construction of creteways for low volume rural roads
- Stabilised fly ash can be used for construction of base sub-base courses. The strength properties of cement stabilised fly ash, shows a significant improvement in terms of California Bearing Ratio (CBR) values.
- Stabilised fly ash base/sub-bases exhibit better durability characteristics.

Mixing of fly ash/cement-fly ash with soil in the field should preferably be carried out by mechanical means using tractor towed rotavator. The success of utilisation depends very much on the quality control measures and adopting proper construction techniques. Use of fly ash in road works results in reduction in construction cost by about 10 to 20 per cent. When fly ash is being used as fill material, the economy achieved is directly related to transportation cost of fly ash. If the lead distance is lesser, considerable savings in construction cost can be achieved. Use of fly ash in pavement construction results in saving precious hard stone aggregates. It should be noted that in case we consider environmental degradation cost due to usage of precious top soil and aggregates from their borrow areas and loss of fertile agricultural land due to ash deposition and creation of soil borrow areas, the savings achieved will work out to be much higher and fly ash usage will be justified even for longer lead distances.

7. CONCLUSIONS

From the above discussion, it can be inferred that use of locally available marginal needs to be accorded its rightful place for construction of low traffic volume rural road. Considerable savings in construction cost and slowing down of environmental degradation can be achieved by adopting use of marginal materials. To achive this objective, following actions are urgently required:

§ Need for collecting and analysing information on international practices and norms on use of marginal materials

§ Preparation of inventory of locally available materials in our country, their characterisation for understanding engineering properties of marginal materials

§ Preparation of realistic design and construction guidelines for marginal material usage in road works, especially for low traffic volume roads by giving adequate consideration to issues like traffic, rainfall, waterlogging, availability of materials, etc

§ Taking up R&D work on usage of such materials, field demonstration projects, collection of performance data of roads constructed using marginal materials, etc.

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PLASTIC WASTE MODIFIED BITUMINOUS SURFACING FOR RURAL ROADS

Dr. P. K. Jain

ABSTRACT

This paper deals with current imperatives for use of plastic waste in bituminous road construction. A review of the available and usable plastic waste in bituminous road constructions is given. The findings of R & D conducted in India and countries abroad are summarized. The pilot studies/projects done on the use of plastic waste are discussed. It is found that shredded plastic waste of the size 2-8 mm may be incorporated conveniently in bituminous mixes used for road constructions. The optimum dose is 0.4-0.5 % by weight of bituminous mix and 6-8% by weight of bitumen. Plastic waste may also be used for up gradations of fly ash for its use as fine aggregate and filler in bituminous road construction.

1. INTRODUCTION

The growth of economy of a country depends largely upon efficient transport system. For socio-economic progress of India, the road network has to be extended to difficult terrains, users and environment. A large number of road infrastructure projects are in progress eventually conventional materials are depleting fast. More importantly, traffic loads carried by the network have been growing more and heavier. Flexible pavements constitute over 90% of network and airfields in our country and surfaced roads are predominantly constructed with the use of bituminous binders. This is largely because these binders have been most suited to the major imperatives of road development, including rural roads due to low initial cost, phased development and availability.

It is well known that under the prevailing heavy traffic and extreme environmental conditions, conventional bituminous surfacing, are not meeting the durability requirement in many situations. Therefore, during the last two decades, highway engineers in India have become increasingly aware that there are some situations for which upgraded bituminous materials are needed. Bituminous materials based on use of modified binders are in practice for construction of surfacing of flexible pavements for enhanced durability since 1999. Modified binders [1-2] are premium binders, which allow the engineer to design and build strong and durable pavement. These binders, as proven all over the world, have better field performance, and are economical when life cycle cost is taken into consideration. It is reported that 20-30% saving can be achieved in maintenance cost using modified binders. IS: 15462-2004 is the only national specification [3] "Rubber and Polymer Modified Bitumen for Road Construction," which specify use of thermoplastic plastomers, thermoplastic elastomers, natural rubber and crumb rubber modified bitumen for road construction.

2. MERITS OF POLYMER MODIFIED MIXES

Modified bituminous mixes have following merits over conventional bituminous mixes [2].

(I) Stiffen binders and mixes at high temperatures to minimize rutting.

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(II) Soften binders at low temperatures to improve relaxation properties and strain tolerance thus minimizing non-load associated thermal cracking.

(III) Improve fatigue resistance especially, where higher strains are imposed on bituminous mixes.

(IV) Improve aggregate-bitumen bonding to reduce stripping.

(V) Improve bituminous pavement durability with reduction in life cycle cost.

(VI) Permit thicker films of bitumen on aggregate in bituminous mixes such as open graded asphalt friction courses (porous asphalt) and stone matrix asphalt.

The cost of these premium materials restricts their use in rural road construction and large scale use in other networks. Plastic waste is potential material for large scale road construction. Imperatives of plastic waste modified mixes for rural roads are therefore discussed in this paper from techno- economic and environmental considerations.

3. PLASTIC WASTE MATERIALS USABLE IN ROADS CONSTRUCTION

The per capita consumption of plastic in developing country like India is about 8-10 kg, which amount to about 12000 million tonnes per annum. The use of plastic is said to be environment friendly in various sectors, but disposal of used plastic specially carry bags generated from domestic solid waste is a matter of concern for environmentalists, as these are source of various problems like cloging of drainage system and fire in forest (Photo 1 to 4). These issues created immense pressure to ban use of plastic carry bags so that disposal problem is minimized. The major constituents of these plastic bags used for packaging are various polyolefin and polyethylene (LLDPE, LDPE, EVA and HDPE).

Disposal of solid waste has only recently become a important feature of Indian life and it was the advent of non-biodegardable plastic. Plastic litter has grown in proportion to the expansion of the plastic industry for domestic product. In the mid of 1980's, Government of India encouraged increase in the national production of plastic so that India would become self-sufficient in petro-chemical products and be able to compete in global market. Over 50% of plastic produced in India is used for packaging purpose. Most of this is discarded once used, and in a country, where traditionally waste was largely unknown this has caused a massive environmental problem. Some additives used in plastic also provoke concern and migrate from plastic to leachate. Plasticizers and pthalates are hazardous substance and have been found in leachate analysis at various concentrations. Better alternatives to solve plastic problem are to accommodate plastic for better roads. Table 1 elaborates various plastic products and their common use, which will be helpful to identify the type of the useful plastic for roads.

Table1. Plastics Characteristics and their Uses

Polymer type	Characteristics	% of total Plastics	Sources
High Density Polyethylene (HDPE)	Tough, Flexible, Translucent	14.6	Beverage bottles, pipe, cable, film, Milk bags
Low Density Polyethylene (LDPE)	Moisture proof, inert	18.3	Trash bags, coatings, plastic bottles
Polyethylene Terphthalate (PET)	Tough, shatter resistant, Gas permeation resistant	2.3	Soft drink, detergent and drink bottles
Polypropylene (PP)	Stiff, heat and chemical resistant	13.2	Battery cases, screw on caps, food tubes, lllm
Polystyrene (PS)	Brittle, clear, rigid, good thermal properties	7.8	House wares, electronics, fast food packaging, food utensils
Polyvinylchloride (PVC)	Strong, clear, brittle unless treated with plasticizers	14.5	Sport goods, luggage, pipes, auto-parts, miscellaneous

Value added products made from plastic waste are given in Table 2.

Table 2. Value Added Products from Plastic Waste

PVC	Shoe sole, floor tiles, conduit pipes, planters
HDPE/LDPE	Carry bags, garbage container, tarpaulins, nursery bags, artificial flowers, irrigation pipes, buckets
PS	Cassette cover, CD covers, adhesives
PET	Fibre/Yarn. Monomer recovery
NYLON	Automotive appliance, fibre/yarn
EPS FOAM	Adhesives
PMMA	Paints/varnish
PP	Yarn/fibre

4. PLASTIC WASTE MODIFIED MIXES GLOBAL SCENARIO

A number of studies [4-10] are conducted by researchers in the recent past for the quest of development of improved bituminous materials using waste plastic. The process developed by Pinoma et al. [4] made the use of thermoplastic materials from domestic and industrial waste such as containers and films comprising polyethylene, polypropylene and other non-biodegradable polymers compatible with bitumen. The major sources of HDPE based waste plastic are high quality carry bags and milk bags in urban area. The key constituents of these materials are different grades of thermoplastic polyethylene. Larry [5] reported reduction in permanent deformation and low temperature cracking of bituminous surfacing using recycled grocery and milk bags in bituminous mixes. Recently, laboratory performance characteristics of bituminous mixes modified by recycled low density polyethylene from waste plastic bags has been reported by a number of investigators [6-12]. Kajal and coworkers [13] investigated the use of waste plastic and copper slag for low cost road construction. Data of these pilot studies have indicated favorable results. Studies on bitumen modification [9] by HDPE (pure) favored lower concentrations of HDPE. Jain and coworkers [14] investigated rutting behavior of bituminous surfacing modified by plastic waste. There is considerable reduction in rutting and deformation of bitumen mixes.

High density polyethylene and low density polyethylene are key constitutes of waste plastic from used milk and grocery bags, which constitute major portion of non biodegradable plastic waste in urban areas. It is concluded from the study (14) that waste plastic can be conveniently used as a modifier in bituminous mixes for sustainable management of plastic waste. The use of 0.4 % waste plastic by weight of mix is optimum and safe besides substantially improving performance properties of bituminous mixes. Therefore, use of waste plastic in bituminous mixes can lead to improvement in life of bituminous surfacing and quality of bituminous surfacing and quality of the life of people. Results (14) of study (Fig 1-3) indicate that incorporation of waste plastic in excess of 0.4% may be sometimes harmful to engineering properties of the bituminous mixes as excessive rutting is observed in laboratory samples. Hence, waste plastic can be used for beneficiation of bituminous mixes, provided waste comprises HDPE or LDPE.

The estimated consumption of waste plastic is 2 tonne/ km (40 mm BC, 7000 m^2). Modification of bituminous mixes with waste plastic is more beneficial for high temperature areas. Waste plastic modified mixes are found to be very useful in mitigating deformation and rutting of bituminous surfacing in hot climate areas [14]. Use of waste plastic in road construction is the best sustainable option for disposal of non-biodegradable plastic waste. Result indicates significant improvement in engineering properties of fly ash based mixes.

5. PROCEDURE FOR PREPARATION AND LAYING OF BITUMINOUS MIX USING WASTE PLASTIC

The plastic waste shall consist of polyethylene, polyolefins and polypropylene and should be free from PVC (Poly Vinyl Chloride). The plastic waste shall be in shredded from of the size 2-3 mm in width and less than 8 mm in length. The Proportion of plastic waste shall be 6-8% by weight of bitumen. The materials shall not be black. The requirement of plastic waste modified binder is given in Table 3.

Table3. Requirements of Binder Modified by PW

Tests	Method	Value
Penetration, 0.1 mm at 25 °C	IS: 1203	30-50
Softening Point, °C	IS: 1205	Minimum 60
Elastic Recovery (%) at 15 °C	IS: 15462	Minimum 25
Viscosity @ 150 °C (poise)	IS: 1206	3-9

The plastic waste modified mix may be prepared in a mini hot mix plant/ batch type hot mix plant depending upon type of construction. For constructions of open graded premix carpet, the required quantity of 13.2 mm aggregate and 11.2 mm aggregate in conformity to IRC: 14-2004 shall be heated to 160 °C and fed to the pug mill of plant. Requisite quantity of plastic waste of required quality shall be added to mixed hot (165°C) aggregate before addition of bitumen (150 °C) The waste plastic and aggregate shall be mixed thoroughly for about 60-120 seconds. The required quantity of bitumen shall be added subsequently and mixed thoroughly for about 120 seconds. The modified mix shall be taken to the laying site in the tippers and spreaded to the required thickness and grade followed by compaction as per procedure given in IRC: 14.

In case, waste plastic is to be used for construction of dense bitumen Macadam/bituminous concrete, only batch type hot mix plant shall be used. The required quantity of waste plastic shall be added by a special device directly to the pug mill before addition of the bitumen to aggregate. The procedure for mixing, transportation and laying shall be same as in case of conventional construction of DBM and BC. The temperature of mixing and rolling shall be higher than conventional bituminous mixes. The broad range of temperature at different stages is given in Table 4.

Table 4. Broad Range of Temperature Requirements for Modified Binders

Stage of Work	Indicated Temperature (°C)
Binder at mixing	150-165
Aggregates temperature	165-175
Mix at mixing plant	150-170
Mix at laying site	130-160
Rolling at laying site	115-155

The suggested design criteria for waste plastic modified mixes are given in Table-5.

Table 5. Design Criteria

Parameters	Requirements		
	Hot Climate	Moderate Climate	Cold Climate
Marshall Stability (75 blows) at 60 °C, kg Minimum	12 kN	10 kN	9 kN
Marshall Flow at 60 °C, mm	2.0-3.5	2.5-4.0	3.0-4.5
Marshall Quotient, kg/mm	350-500	300-450	250-400
Voids in compacted mix, %	3-5	3-5	3-5
Requirement of retained stability after 24 hours in water at 60 °C, % minimum	90	95	95
Rutting at 45 °C, maximum, mm	4	6	8

6. CASE STUDIES

Several roads in Delhi have been constructed using plastic waste modified mixes. These roads mere resurfaced with 40 mm BC of waste plastic modified mix meeting design criteria given in Table 5. Some of these are listed below:

1) Maa Anand Mai Marg
2) Road No 72 and 72 Extension in East Delhi
3) Road No 71 in East Delhi
4) Road No 75 B in East Delhi
5) Road No 62 in East Delhi
6) Road in DSIDC, Bawana
7) GD Birla Marg in South Delhi.

Views of these roads are given in Photos 5 to 12.

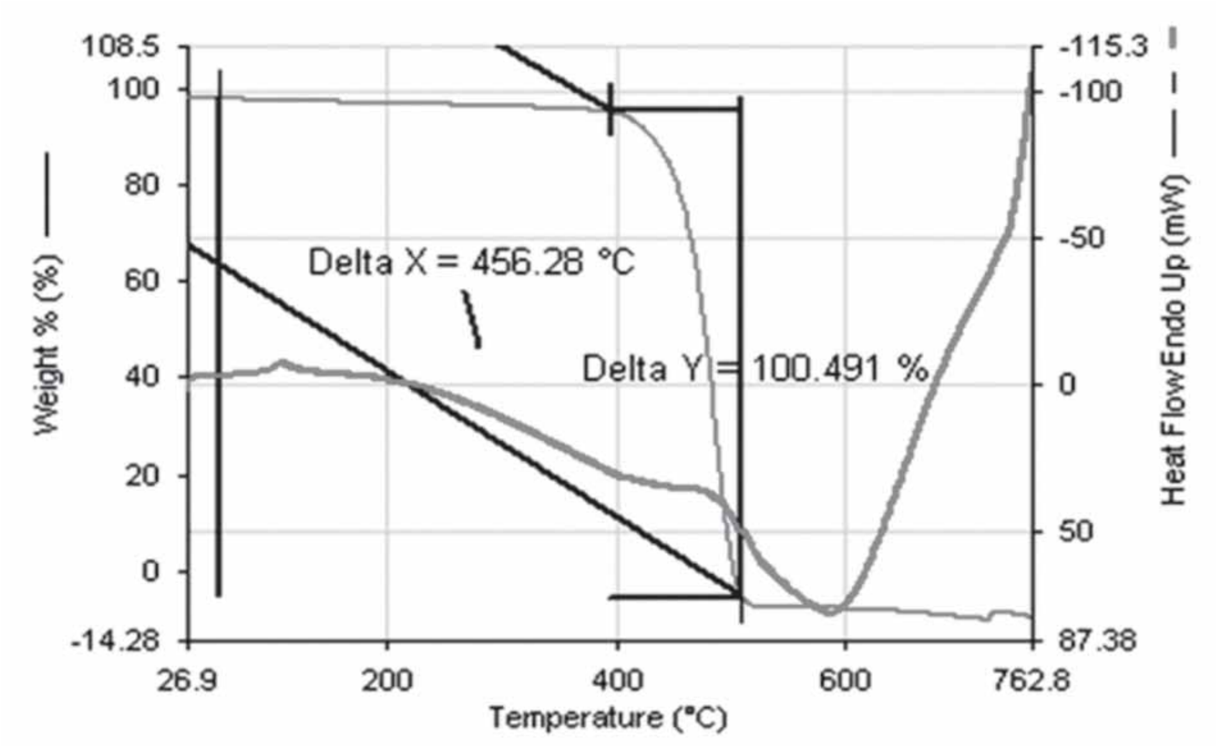

Fig. 1 Thermal Analysis of Typical Plastic Waste

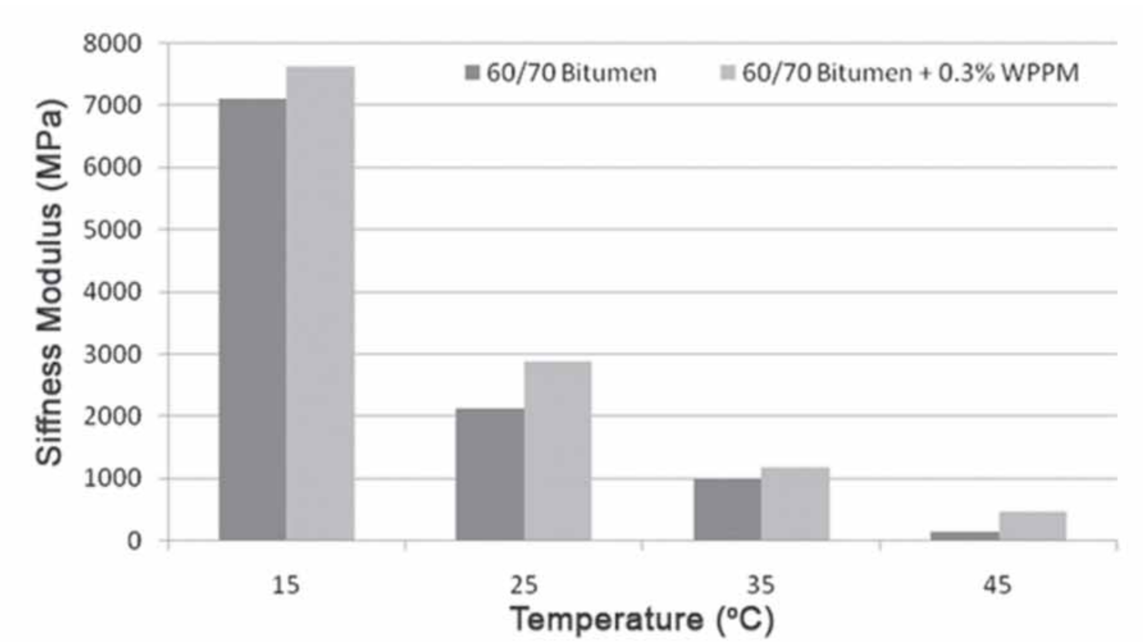

Fig 2. Stiffness Modulus Values

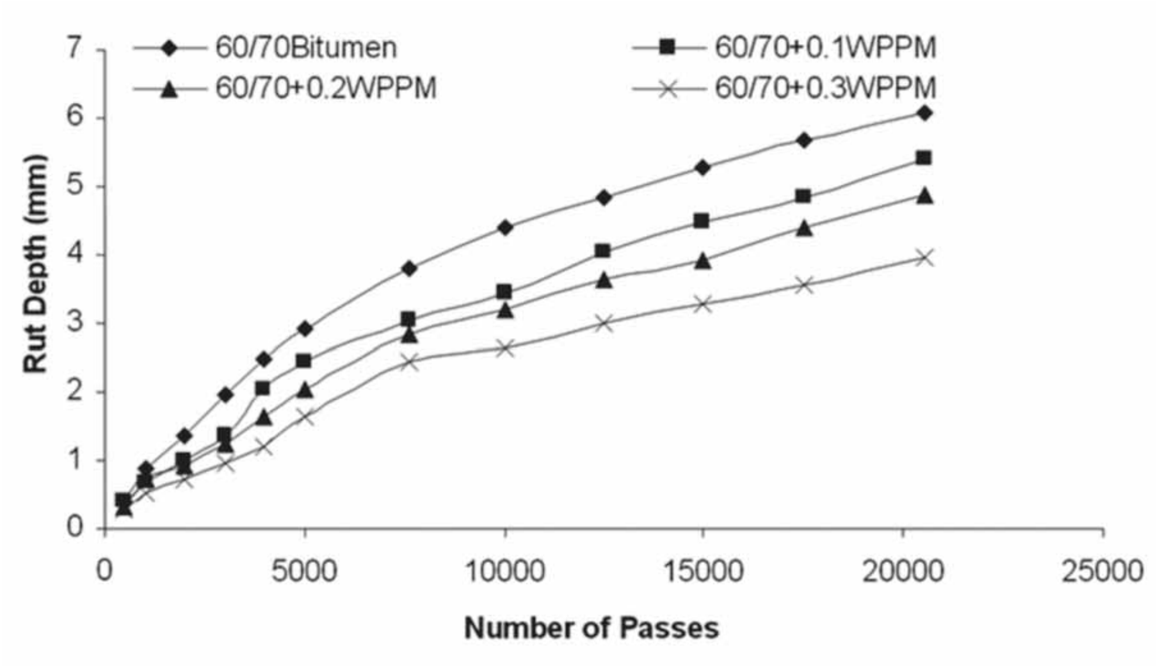

Fig. 3 Rutting Properties of WP Modified Mix

7. CONCLUSIONS

1. Use waste plastic in bituminous mixes improves properties and performance of roads
2. Plastic waste modified mixes can also be used for construction for rural roads
3. The optimum dose of plastic waste is 0.4% by weight of bituminous mixture and 8% by weight of bitumen.
4. Use of waste plastic in roads is ideal disposal solution.

ACKNOWLEDGEMENTS

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Photo 1

Photo 2

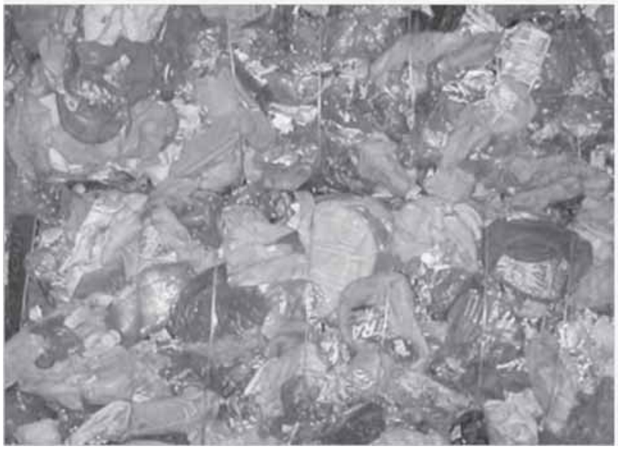

Photo 3

Photo 4

Photo 5

Photo 6

Photo 7

Photo 8

Photo 9

Photo 10

Photo 11

Photo 12

LABORATORY STUDIES ON BIO-ENZYME STABILIZED LATERITIC SOIL AS A HIGHWAY MATERIAL

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ABSTRACT

Soil stabilization is a technique to improve the weak soils and making them to meet certain requirements of the specific engineering projects. The type of soils available in Dakshina Kannada region of Karnataka state is Lateritic and Lithomarge clay. The plasticity index is much more due to the presence of high percentage of silt and clay content. In this present study, the effectiveness of enzyme in soil stabilization is investigated through laboratory experiments. The enzyme when added to water and mixed with soil alters the engineering properties depending upon the type of the soil and dosage of enzyme. These enzymes are liquid additives, which act on the soil to reduce the voids between soil particles and minimize absorbed water in the soil for maximum compaction. In this study the pure laterite soil is again blended with coarse grained sand and this mix is further stabilized using a Bio-Enzyme. For both cases important properties such as Index properties, Compaction characteristics, Shear strength parameters, CBR values and Fatigue behavior are studied. Correlations between different geotechnical properties and improvement in the soil properties with different dosages of additives are derived. The results obtained indicate that there is an improvement in almost all properties with the addition of Bio-Enzymes.

1. INTRODUCTION

The growth of the population has created a need for better and economical vehicular operation which requires good highway having proper geometric design, pavement condition and maintenance. The highways have to be maintained so that comfort, convenience and safety are provided to the traveling public. The pavements along the national and state highways in the costal belt of Karnataka are damaged due to the poor strength of soil used and low permeability. Hence it is necessary to have a proper diagnostic study of the soil to be used as subbase. Cost effective roads are very vital for economical growth in any country. There is an urgent need to identify new materials to improve the road structure and to expand the road network. Commonly used materials are fast depleting and this has led to an increase in the cost of construction. Hence, the search for new materials and improved techniques to process the local materials has received an increased impetus. When poor quality soil is available at the construction site, the best option is to modify the properties of the soil so that it meets the pavement design requirements. This has led to the development of soil stabilization techniques. Since the nature and properties of natural soil vary widely, a suitable stabilization technique has to be adopted for a particular

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situation after considering the soil properties. Soil improvement by mechanical or chemical means is widely adopted. In order to stabilize soils for improving strength and durability, a number of chemical additives, both inorganic and organic, have also been used. Recently bio-enzymes have emerged as a new chemical for soil stabilization. Bio-enzymes are chemical, organic, and liquid concentrated substances which are used to improve the stability of soil subbase of pavement structures.

1.1 Bio-Enzymes as Soil Stabilizers in Road Construction

Bio-enzyme is a natural, non-toxic, non-flammable, non-corrosive liquid enzyme formulation fermented from vegetable extracts that improves the engineering properties of soil, facilitates higher soil compaction and increases strength. Enzymes catalyze the reactions between the clay and the organic cations and accelerate the cat-ionic exchange process to reduce adsorbed layer thickness. For other types of chemical stabilization, chemicals are mixed with soil, which is difficult to mix thoroughly, but Bio-enzyme is easy to use as it can be mixed with water at optimum moisture content and then it is sprayed over soil and compacted. Bio-enzyme from Australia is a natural, non-toxic bio-degradable liquid concentrate that mixes easily in water for application with standard water spraying equipment. By altering the physical and chemical characteristics of soil, materials treated with Bio-Enzyme retain higher performance levels and extended life span. Bio-Enzyme may be used to increase the Maximum Dry Density (MDD) and Unconfined Compressive Strength (UCS) values of a marginal material to achieve specified standards for a base course. Bio-Enzyme manufactured in USA and Netherlands also increases the unconfined compressive strength (UCS) and California Bearing Ratio (CBR) of sub-grade soil. Among the soil materials stabilized by the bio-enzymes in the trials are sandy clay, silty clay, sandy silt, plastic and non-plastic clay, sandy loam, fine loam, and loam mixed with clay. The dosage levels of the bio-enzymes vary from 1 to 5 liters for 5 m^3 of soil depending on the soil type, soil characteristics, and product concentration. The amount of dilution water depends on in-situ moisture content of soil.

1.2 Mechanism of Soil Stabilization By Bio-Enzyme

In clay water mixture positively charged ions (cations) are present around the clay particles, creating a film of water around the clay particle that remains attached or adsorbed on the clay surface. The adsorbed water or double layer gives clay particles their plasticity. In some cases the clay can swell and the size of double layer increases, but it can be reduced by drying. Therefore, to truly improve the soil properties, it is necessary to permanently reduce the thickness of double layer. Cation exchange processes can accomplish this. By utilizing fermentation processes specific micro-organisms can produce stabilizing enzyme in large quantity. These soil-stabilizing enzymes catalyze the reactions between the clay and the organic cat-ions and accelerate the cat-ionic exchange without becoming part of the end product.

1.3 Bioenzyme, a Bio-Enzymatic Soil Stabilizer

Bioenzyme is a natural, non-toxic liquid, formulated using vegetable extracts. Apart from being a concept accepted the world over as a sound and resourceful road building practice, which completely replaces the conventional granular base and the granular sub base, it emphasizes on strength, performance and higher resistance towards deformation. Organic enzymes come in liquid form. They are perfectly soluble in water, brown in color and smell of molasses. The specific weight is similar or equal to that of water. The pH level is between 4.3 and 4.6. Their aroma has no effect. Neither gloves nor masks are required during handling but it can cause irritation to the eyes. If they are to be stored for long periods of time without losing any of their properties, it is necessary to maintain a temperature of 55^0 C. There is no risk of decay. The enzymes react with oxidizing agents. Bioenzyme is specially formulated to modify the engineering properties of soil. They require dilution in water before application. Bioenzyme acts to reduce the voids between soil particles and minimize absorbed water in the soil for maximum compaction. This decreases the swelling capacity of the soil particles and reduces permeability. The application of Bioenzyme enhances weather resistance and increases load bearing capacity of soils. These features are particularly evident in fine-grained soils such as clay in which the formulation affects the swelling and shrinking behavior. This formulation has the ability to change the matrix of the soil so that after compaction the soil loses its ability to reabsorb water and the mechanical benefits of compaction are not lost even after water is reapplied to the compacted soil. Once the enzyme reacts with the soil, the change is permanent and the product is bio-degradable.

2. LITERATURE REVIEW

Lacuoture and Gonzalez (1995) conducted a comprehensive study of the Bioenzyme soil stabilizer product and its effectiveness on sub-base and sub-grade soils. The variation in properties was observed over a short period only and it was found that in cohesive soils there was no major variation in properties during the early days but the soil showed improved performance progressively. Hitam and Yusof(1998) of Palm Oil Research Institute of Malaysia conducted field studies on improvement on plantation roads. Bioenzyme was treated to 27.2 km of the road, which was having serious problems during the monsoon season or after heavy downpour. The sections were then monitored on the surface erosion due to rainwater and wear due to usage. After two monsoon seasons the road was found to be in very good condition in spite of large exposure to heavy rainfall. No surface damage was observed, thus requiring no repair works to the road section. Bioenzyme stabilization can convert the road to an all weather road that has minimum destruction in hot and wet season. Brazetti and Murphy (2000) conducted field experiments in Brazil to study the use of Bioenzyme as the bio-enzyme stabilizer for road construction. The selected soils were sandy clay, silty clay, sandy silt, plastic and non-plastic clay, sandy loam, loam mixed with clay, soil mixtures with pieces of recycled pavement. The field stretches were periodically tested with DCP (Dynamic Cone Penetrometer) equipment. After the evaluation it was concluded that the enzyme stabilization is a good technique for the effective and economic solution for pavement construction. Andrew et al (2003) conducted laboratory scale testing program to evaluate the effectiveness of enzyme treatment on sub grade soil. The effectiveness of enzyme treatment was evaluated on the basis of statistical measurement of change in CBR, strength, soil stiffness and soil modulus. The CBR test appears to be a relatively poor indicator of direct soil strength for testing conditions. Bergmann (2000) concluded that the Bio-Enzymes require some clay content in the aggregate material in order to create the reaction that will strengthen the material. The successful stabilization could be achieved with as little as 2% clay in the aggregate material but best result seems to be achieved with 10 to 15% clay. It was reported that after one week, two week, three week, and 14 week periods CBR was found as 37, 62, 66 and 100 respectively as compared to 28% of untreated soil.

3. EXPERIMENTAL INVESTIGATION

To assess the suitability of Bio-Enzyme as soil stabilizer, laboratory tests were conducted to determine the engineering properties and strength characteristics of lateritic soil and blended lateritic soil with and without stabilization with bio-enzyme. The lateritic soil and blended lateritic soil samples considered for study were first tested for engineering properties and samples were then tested for strength parameters such as CBR and unconfined compressive strength, without stabilization and with stabilization for a curing period of 2 weeks, 3 weeks and 4 weeks. In the above tests bio-enzyme was used for stabilization, all the tests were performed as per relevant I.S. Specifications.

3.1 Materials Used & Tests Conducted

The materials used for the tests include the lateritic soil, sand and Bio-Enzyme. The lateritic soil obtained from field was tested in the laboratory for the properties like specific gravity, grain size distribution, consistency limits, compaction, unconfined compressive strength, and CBR and permeability tests. The results are tabulated in Table 1.

Table 1. Properties of Lateritic soil

Sl. No.	Property	Value
1	Specific gravity	2.45
2.	GRAIN SIZE DISTRIBUTION	
	Gravel (%)	19
	Sand (%)	50
	Silt (%)	29
	Clay (%)	2
	Co-efficient of Uniformity, C_u	115.4
	Co-efficient of Curvature, C_c	0.74
3.	CONSISTANCY LIMITS	
	Liquid Limit (%)	35
	Plastic Limit (%)	25
	Plasticity Index (%)	10
	Shrinkage Limit (%)	16.6
4.	IS Soil Classification	SM-GM
5.	ENGINEERING PROPERTIES	
	IS Light Compactiona) Max. Dry Density, kN/m^3	19.32
	b) OMC (%)	13.50
	IS Heavy Compactiona) Max. Dry Density, kN/m^3	19.95
	b) OMC (%)	11.40
6.	CBR (%)	
	IS Light Compaction (at OMC)	10
	IS Light Compaction (Soaked)	04
	IS Heavy Compaction(at OMC)	14
	IS Heavy Compaction (Soaked)	08
7.	UNCONFINED COMPRESSIVE STRENGTH	
	a) IS Light Compaction (kPa)	108
	b) IS heavy Compaction (kPa)	142
8.	CO-EFFICIENT OF PERMEABILITY	
	a) IS Light Compaction (m/s)	4.78×10^{-8}
	b) IS Heavy Compaction (m/s)	2.87×10^{-8}

Table 2. Properties of sand

Description	Test value
Specific gravity	2.64
Fineness modulus	2.18
Loose Density(kN/m^3)	14.13
Vibrated Dense Density(kN/m^3)	17.13
Grain size analysis	
Gravel (%)	2
Sand (%)Silt (%)	98trace
Clay (%)	0
Cu	2
Cc	0.83
Direct Shear Test	
Angle of internal friction (Ø)	44º 5´
Degrees Cohesion (kN/m^3) (c)	0
Grading as per IS: 383-1970	Zone-II

3.2 Tests on Blending of Soil

The coarse grained soil (sand) collected is sieved and only coarse sand passing through 4.75 mm sieve and retained on 425 micron is used for adding to the test samples in different percentages. The requisite quantity of sand to be replaced for the effective blending of soil is determined in the laboratory by changing the percentage of sand till the desired limits are achieved. Consistency limit tests were carried out on soil, soil-sand mixes to ensure the specifications specified by **MoRTH**, IRC SP-20, 2002.

3.2.1 Compaction Tests

Compaction tests were conducted on the soil blend (lateritic soil- sand). On the soil, modified proctor's test was conducted according to relevant IS specifications (IS: 2720 (Part8)-1980). The results of these are tabulated in Table.3.

Table 3. Compaction, CBR and Permeability results for Blended Soil

Compaction, CBR and Permeability test results					
Lateritic soil (%)	**Sand (%)**	**OMC (%)**	**MDD (kN/m^3)**	**CBR (%) (Soaked)**	**Coefficient of Permeability, K (m/s)**
100	0	11.4	19.95	8	2.87×10^{-8}
90	10	11.0	20.35	10	5.75×10^{-8}
80	20	10.7	20.61	14	10.5×10^{-8}
70	30	10.4	20.80	18	18.4×10^{-8}
60	40	9.98	21.39	22	26.8×10^{-8}
50	50	10.2	21.10	20	57.4×10^{-8}
40	60	11.0	20.60	14	89.6×10^{-8}

3.3 Stabilization Using Bio-Enzyme

A bio-enzymatic soil stabilizer improves the engineering properties of the locally available soil for the use of construction of roads. Both laboratory and field studies conducted in India have shown that soil stabilization with Bioenzyme provides such a positive improvements in various soil types that the use of Bioenzyme offers a substantial reduction in the construction cost of roads. Varying quantities of stabilizers can cause different effect in the same soil sample. Insufficient quantity of Bioenzyme may lead to less stabilization of the soil where as excess quantities may result the stabilization ineffective and uneconomical. Hence, to determine the optimum quantity of Bioenzyme for best results, CBR tests were conducted on each of the soil samples with varying quantity of Bioenzyme. Depending on the soil gradation, clay content and plasticity index of the soil, the required dosage of Bioenzyme for mixing with soil, as suggested by supplying company is given below.

Table 4. Enzyme Dosages

Dosage	200ml/m^3 of soil	ml/kg of soil
1	3.5	0.029
2	3.0	0.0338
3	2.5	0.0406
4	2.0	0.050

Dosage calculations are shown in Appendix 1.

3.3.1 CBR and Unconfined Compressive Strength Tests

Soil was treated with 4 dosages of enzyme at optimum moisture content. CBR moulds were prepared by modified proctor method and kept in airtight bags for testing on its 7th, 14th, 21st and 28th days curing. Later these moulds were kept in soaked condition for 4 days and then tested for CBR.

Unconfined compressive strength of lateritic soil was evaluated by stabilization with variable dosages of enzyme for one, two, three and four curing weeks. The specimens were prepared and kept in desecrator to retain moisture of the sample so that reaction between soil particle and Bioenzyme may be continued. CBR and UCS values of lateritic soil with different enzyme dosages in various curing days are given in Table 5.

Table 5. CBR and UCS values of Soil treated with Enzyme

Dosage	Treated Weeks			
	1st	2nd	3rd	4th
CBR %				
Un treated 08				
1	17	20	21	23
2	20	23	25	27
3	23	25	27	29
4	25	27	29	31
UCS of soil in (kPa) for period of treatment				
Un Treated 142				
1	205	272	343	447
2	262	324	398	513
3	330	434	532	716
4	428	513	607	782

3.3.3 Permeability Tests

Permeability tests were conducted on soil treated with enzyme at optimum moisture content. Permeability moulds were prepared and kept in airtight bags for testing on its 7th, 14th, 21st and 28th days curing. Later these moulds were fixed to permeameter and then tested. The test results have been given in Table 7.

Table 7. Coefficient of Permeability of soil with Enzyme

Dosage	Treated Weeks			
	1st	2nd	3rd	4th
Coefficient of Permeability (K) m/sec (x10-8)				
1	2.87	2.87	2.63	2.63
2	2.63	2.39	2.39	2.39
3	1.91	1.91	1.91	1.67
4	1.91	1.67	1.67	1.67

3.4 Effect of Bioenzyme and Test results on Enzyme Treated Blend Soil

The CBR values of different percentage of blended soil were studied by treated with enzyme dosage of 200 ml/ 2 m^3 for one, two, three and four weeks of curing. The effect of enzyme on CBR values of lateritic soil with variable percentage of sand for a period of one to four weeks of curing are shown in Table 8. The higher enzyme dosage 4 is used for treating blended soil. From the test results it was found that as sand content increases beyond 10%, the CBR value decreases for enzyme treated soils.

Table 8. CBR values of Blended soil with Enzyme

Soil blendsoil -sand%	Treated Weeks			
	1st	2nd	3rd	4th
	CBR %			
100-0	25	29	30	31
90-10	27	30	31	32
80-20	24	29	30	31
70-30	22	27	28	30
60-40	21	24	27	28

This blended soil is further stabilized by enzyme, after one week curing this value increased to 27% and after four weeks curing this value was increased to 32%. Further addition of sand and enzyme there is decrease in CBR values. When CBR value is compared to untreated blended soil there is an increase in CBR value at higher curing periods. It shows that 10 % of blended soil improves the CBR by 238 % after one week of curing and further improves by 300 % after four weeks of curing. Similarly for 20 % of blended soil the CBR improves by 200 % to 288 %, for 30 % of blended soil the CBR improves by 175 % to 275 % and for 40 % of blended soil the CBR improves by 163 % to 250 % after curing for one week to four weeks. It indicates that CBR value improved to a maximum of 300 % for 10 % blended soil. The optimum sand content to replace lateritic soil when further treated with enzyme was 10%. The CBR values are maximum at 10% as replaced. For the rest of the blending the CBR values are lesser. However, as the curing period increases the CBR values of all the blends are increasing further.

4. FATIGUE ANALYSIS

4.1 Laboratory Fatigue Testing

To investigate on the performance of enzyme stabilized Soils, the enzyme stabilized specimens were exposed to the repeated loading in the laboratory. For this purpose the laboratory experiments are conducted in a fatigue testing apparatus and the specimens are subjected to number of repeated loads. The number of loading cycles varied depending curing Period and other excitation parameters such as stress, frequency of loading and type of wave form etc. This section describes the methodology adopted for this purpose.

a) Specimen Preparation and curing

The type of specimen tested for fatigue capacity of the enzyme stabilized specimen is similar to the one tested for their unconfined compression test. A cylindrical specimen of length to diameter ratio of 2 is used.

b) Testing Equipment

The Fatigue test equipment that is capable of applying the repeated loads at a frequency 0 to 12 Hz is used in the present investigation. The equipment is procured from SPRANKTRONICS, Bangalore.

The main components of the test set-up are:

i. Loading system including loading frame and load sensing device

ii. Control system including function generator

iii. Data Acquisition system

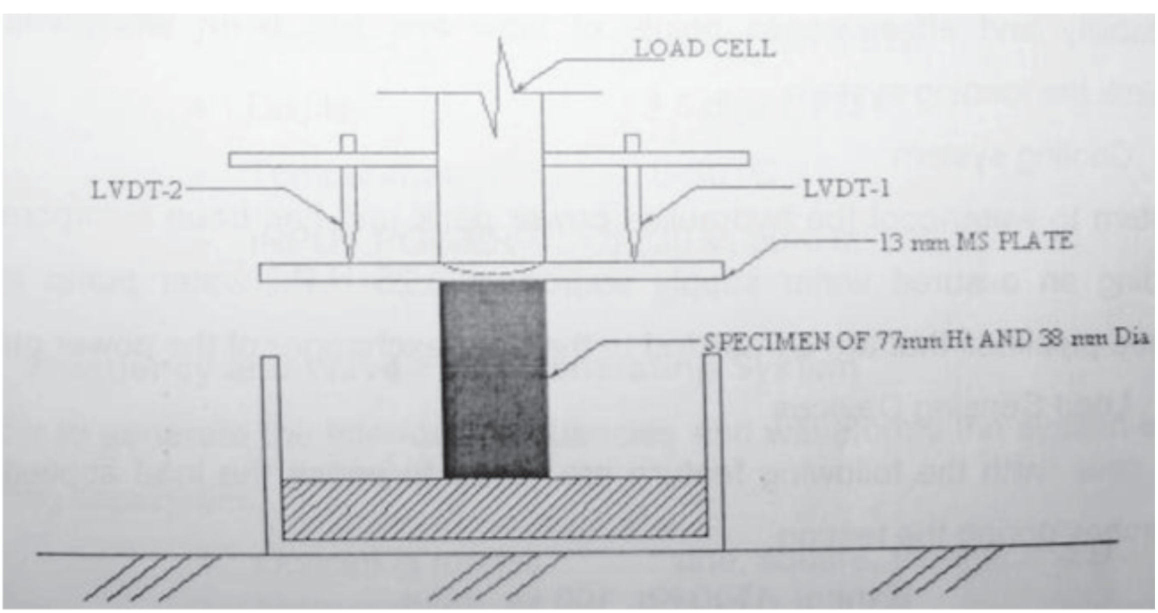

Fig. 1 Schematic Diagram of Accelerated Fatigue Load Test Set-up

c) Testing Procedure

All the fatigue loading tests are conducted on cylindrical specimens using fatigue testing equipment. For this propose the following testing procedure is adopted

- The Cylindrical specimen is mounted on the loading frame and the Deflection sensing transducers (LVDT) are set to read the deformation of the specimen. The load cell is brought in contact with the specimen surface.
- In the control unit through the dedicated software, the selected loading stress level, frequency of loading and the type of wave form are fed in to the loading device
- The loading system and the data acquisition system is switched on simultaneously and the process of fatigue load application on the test specimen is initiated
- The repeated loading, at the designated excitation level (i.e. at the selected stress level and frequency) is continued till the failure of the test specimen.
- The data acquisition system continuously record the vertical deformation of the test specimen with cycles of loading until the failure and the output file is given noted as a Result file. The failure pattern of the test specimen is noted.

4.2 Effect of Enzyme on Fatigue Characteristics of Stabilized Soils

To bring out the effect of enzyme on the performance of stabilized soils, when subjected to repeated loads, experiments are conducted on all the two types of soils. A comparative study between unstabilized and stabilized soils indicates that the enzyme stabilization is effective in improving the strength. The enzyme treated specimens experience a large number of loading cycles, before failure whereas their untreated counterpart (shown in Table 9) failed within a few number of loading cycles. This trend of results is observed for the two soils tested under different Curing period and stress level. These experimental results clearly shows that the untreated soil specimens which were not capable of taking any loading cycles develop itself into a material, upon treatment with enzyme, that are capable of taking considerable number of repetitive loading.

To bring out the influence of various parameters viz., the percentage of enzyme, stress level and curing period, the maximum number of loading cycles a specimen capable of taking before being failed is considered as “Fatigue life” in this study. The enzyme treated lateritic soil specimen failed at loading cycles 15892 and 21728 when the stress level is 30% for enzyme dosage 1 and 2 respectively (for curing period of 8 weeks). These numbers of loading cycles is referred as “Fatigue Life” of the respective specimen at the defined stress level. In further discussion the “Fatigue Life” is taken as the parameters to bring out the influence of various parameters like dosage type, Curing period and type of soil.

Table 9. Fatigue life of untreated soil specimens at different stress levels

Curing Period (Weeks)		0	1	2	3	4	6	8
		Fatigue life (No. of cycles)						
Applied Stress (% of UCC Strength)	100	1	1	1	1	2	1	1
	80	1	1	1	1	2	1	3
	60	1	2	1	1	2	1	2
	50	2	2	1	2	4	4	4
	40	2	2	3	3	4	4	4
	30	3	3	3	3	4	3	5

4.3 Effect of Enzyme Content on Fatigue Life

The fatigue tests are conducted at frequency of 2Hz on stabilized soils at various stress level. The soil samples on treated with bio-enzyme with different dosage viz. 1, 2, 3 & 4. The test results are presented in Table 10 and Fig.2

Table 10. Fatigue Life for different Enzyme dosages at varying Stress levels

Curing period in weeks (30% Stress Level)								
Enzyme dosage		0	1	2	3	4	6	8
1	Fatigue Life (No. of cycles)	54564	53781	51782	42682	36752	23574	15892
2		70025	69342	65672	59782	48924	34672	21728
3		68352	67451	63345	51672	41962	28734	18893
4		59189	58934	55672	44672	37673	24567	13892
Curing period in weeks (40% Stress Level)								
1	Fatigue Life (No. of cycles)	52378	51895	47872	41783	32712	21982	13692
2		65257	65892	61724	54625	45389	31572	18458
3		62290	61783	57871	47721	37931	25258	15713
4		55289	53982	50751	42472	35489	23891	11902
Curing period in weeks (50% Stress Level)								
1	Fatigue Life (No. of cycles)	49324	48201	42782	37718	29721	19574	12432
2		63682	61892	56729	51252	42472	26472	15627
3		59652	58378	56322	45623	35258	22782	14893
4		50426	48299	45372	40762	32423	21362	10892
Curing period in weeks (60% Stress Level)								
1	Fatigue Life (No. of cycles)	47782	46101	43285	35673	25782	17625	11343
2		59745	58902	54783	48792	39892	24672	12628
3		58782	56781	53784	42892	33782	20892	11892
4		51785	47523	43861	44672	29482	18672	9726
Curing period in weeks (80% Stress Level)								
1	Fatigue Life (No. of cycles)	44753	44723	40782	33777	22667	15371	9745
2		57562	56721	52784	45781	35783	21783	10784
3		56834	55902	50945	40732	29681	17834	9351
4		49823	48784	43889	35872	25963	15632	7867

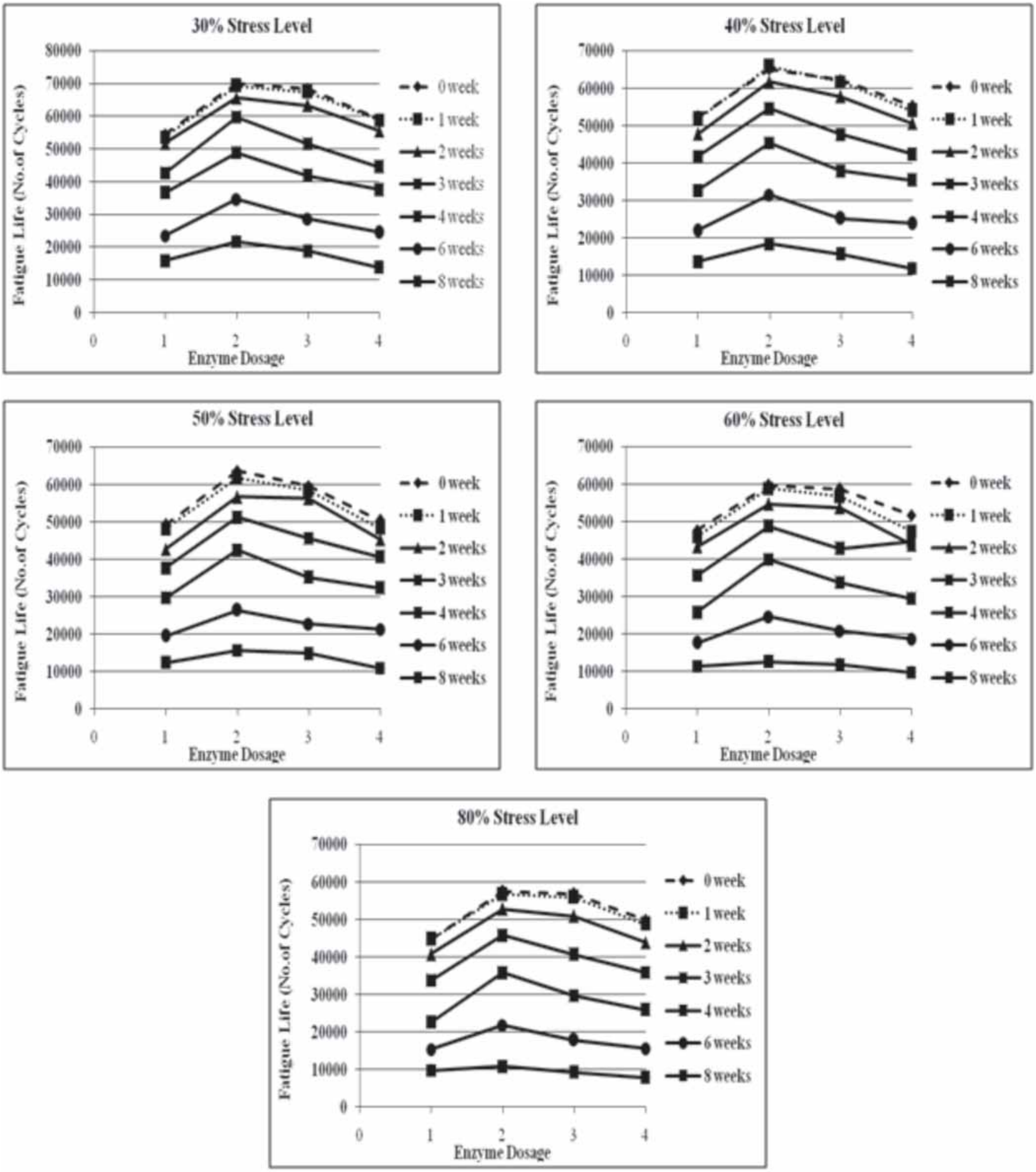

Fig. 2. Effect of Enzyme content on Fatigue life of Enzyme treated Lateritic soil specimen at different stress level and 2Hz Frequency

Fig.2 presents the data for stabilized Lateritic soil subjected to repeated loads at 30,40,50,60 and 80% stress level and at frequency of 2 Hz. The figures include the experimental results conducted with different curing periods also. The fatigue life of the stabilized soil initially increases as the Enzyme content increase. The increase is upto 4% Enzyme content and the further increase in Enzyme content, the fatigue life of the stabilized soil reduces. This trend is observed for the entire specimen tested at different stress level. It is also observed that for different curing periods the trend remains same.

5. FIELD TRIAL

To confirm the test results obtained in the laboratory the investigations were conducted in the field by constructing a road with enzyme stabilized lateritic soil for a stretch of 1350 meter length and 3 m wide. The road selected for the experimental investigation was at Nancharu-Kokkarne Road, Udupi District. The construction of road segment for a length of 1.35 km was done under "Pradan Mantri Grama Sadak Yojana" (PMGSY) scheme. The enzyme stabilized soil was used as layer material for construction of pavement. The site condition is studied thoroughly before the use of enzyme. The purpose of conducting Mild tests on the constructed trial road segment and the ideology behind the field test cycle was to obtain information on the behavior of the enzyme treated road segment in a realistic usage environ-ment, after which a recommendation can be made regarding the effectiveness of this new technology used in the construction of the trial road. With regards to the necessity to reach a conclusion on the usefulness of this bio enzymatic soil stabilizer for the construction of roads under Indian climate and soil conditions, interpretation of the field test results will have to determine the effectiveness of this method.

5.1 Existing Soil Investigation

The site condition was studied thoroughly before the use of bio enzyme. Soil investigation was carried out to know the geotechnical properties of the soil. Results are shown in Table 11.

5.2 Construction and Analysis of Enzyme Stabilised Road

The road surface was scarified to the desired thickness. Correct volume of enzyme was mixed with water and the solution was uniformly distributed onto the road section. The moist material was mixed and the treated bed was compacted. After preparing the road surface with the bio enzyme treated soil Dynamic Cone Penetration tests were conducted at different points and the results are given in Table 12.

Table 11. Index properties of the soil at the site before the application of Enzyme

Sl. No.	Index Property	Value
1.	Specific Gravity	2.55
2.	Atterberg's LimitsLiquid Limit, %Plastic Limit, % Plasticity Index	382513
3.	Light Compaction TestMDD, gm/ccOMC, %	1.7614.55
4.	Heavy Compaction TestMDD, gm/ccOMC, %	1.8612.5
5.	CBR TestFor Light Compaction, %For Heavy Compaction, %	1012

Table 12. Results of Dynamic Cone Penetration Test conducted after enzyme treatment

Site No	1		2		3		4		5	
Sl. No.	No. of blows	Penetration in cm	No. of blows	Penetration in cm	No. of blows	Penetration in cm	No. of blows	Penetration in cm	No. of blows	Penetration in cm
1	0	3.7	0	3.6	0	3.3	0	3.3	0	3.4
2	3	5.6	3	5.3	3	4.5	3	4.5	3	4.5
3	6	6.5	6	5.8	6	5.0	6	5.0	6	5.0
4	9	6.5	9	6.1	9	5.3	9	5.5	9	5.4
5	12	7.4	12	6.1	12	5.7	12	5.9	12	5.7
6	15	7.4	15	6.1	15	6.0	15	6.1	15	5.8
7	18	7.4	18	6.3	18	6.2	18	6.2	18	6.0
8	21	7.5	21	6.6	21	6.5	21	6.4	21	6.1
9	24	7.5	24	6.7	24	6.7	24	6.4	24	6.3
10	27	7.7	27	6.8	27	7.0	27	6.4	27	6.5
Final reading	30	7.8	30	7.0	30	7.2	30	6.7	30	6.5
DCP		1.37 mm		1.14mm		1.3mm		1.14mm		1.13mm

The DCP test conducted at 5 points of enzyme treated soil shows that DCP value is less than 3mm at all points and it clearly indicates that the CBR value is more than 100%**.** It is evident from the that result that the surface soil treated with enzyme has substantially improved CBR values as compared to untreated soil.

5.3 Long Term Effect of Enzyme on Soil

To verify the long term effect of the enzyme on soil stability, the road constructed with enzyme stabilized soil is kept with out any bituminous top layer for more than 8 months. After one week the road was open for traffic. Field CBR was conducted during the month of Feb. 2009 after allowing the road for one rainy season. The results indicate that the CBR values obtained in the field are more than 80%. It clearly indicates that the long term durability of Bioenzyme treated soil.

Table 13. Field CBR Values

Trail No	CBR Value(%)
1	131
2	153
3	138

6. CONCLUSIONS

Based on the tests conducted the following conclusions have been drawn.

1. The lateritic soil properties have been much improved by stabilizing with enzyme dosage of 200 ml/ 2 m^3 of soil.

2. For a higher dosage of 200 ml/ 2 m^3 of soil, the CBR value of lateritic soil increased by 300 % after four weeks of curing, unconfined compressive strength of the soil increased by 450 and permeability decreases by 42 %.

3. The lateritic soil properties have been improved by adding sand. When more than 20 % of soil is replaced by sand, consistency limits and CBR values were found to have met the specified limits (LL< 25 %, PI< 6% and soaked CBR > 20 %) of sub base. It is observed that CBR value increases with increase in percentage of sand up to 175%.

4. The CBR values of the enzyme treated soil blend decreases with increase in sand content. The CBR value of blended soil increased by 300% with 10 % sand with a dosage of 200 ml/ 2 m^3 of soil.

5. By comparing CBR values of the unblended and blended soil after enzyme treatment it was found that enzyme is not effective for soil containing higher percent of cohesion less soil.

6. The fatigue life increases for lateritic soil with an enzyme dosage of 4%. Beyond this dosage the improvement in fatigue life is very insignificant.

7. The fatigue life of the stabilized soil increases upto a curing period of 4 weeks and beyond that there is a marginal increase.

8. Field study conducted on National Highway also proved that the bio enzyme treated soil is having substantially good CBR values as compared to ordinary soil.

9. The results indicate that the CBR values obtained in the field are more than 100%. It clearly indicates that the long term durability of Bioenzyme treated soil.

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APPENDIX 1

Dosages specified by the company for Lateritic soil was 200ml for bulk volume 3.5 m^3 to 2 m^3 of soil.

Bulk Density of Lateritic soil = 1.97 g/cc, Bulk Density = Weight / Volume.

Weight = Bulk Density x Volume

For Dosage 1,

200 ml for 3.5 m^3 of soil = 1.97x 3.5x 1000 = 6895 kg of soil, For 1 kg = 0.029 ml of Enzyme

For Dosage 2,

200 ml for 3.0 m^3 of soil = 1.97x 3.0x 1000 = 5910 kg of soil, For 1 kg = 0.0338 ml of Enzyme

For Dosage 3,

200 ml for 2.5 m^3 of soil = 1.97x 2.5x 1000 = 4925 kg of soil, For 1 kg = 0.0406 ml of Enzyme

For Dosage 4,

200 ml for 2.0 m^3 of soil = 1.97x 2.0x 1000 = 3940 kg of soil, For 1 kg = 0.050 ml of Enzyme

Appendix

Presentations by Material Supplier

Sl. No	Material	Name of Organization
1.	RBI-81- Soil Stabilizer	Alchemist Touchnolgy, Limited
2.	Soil Tech MK-III Polymer Soil Stabilizer	India Polyroads Pvt. Ltd.
3.	Zycosoil, Nano Technology	Zydexindustries
4.	TechFab Wooven Geotextiles	TechFab India Industries Ltd
5.	Zym-Tec.	i-Tech India
6.	CONSOLID 444	M/s Grace & Sachi
7.	Pre –Fabricated Bridges	Hindustan Prefab Limited
8.	Bailey Bridges	Garden Reach Shipbuilders & Engineers Ltd
9.	Roller Compacted Concrete and Self Compacting Concrete.	National Council for Cement and Building Materials

Achievements

About 1,13,600 habitations covered requiring construction/upgradation of about 439 thousands km of roads with an investment of about ₹ 126 thousands crores

Over 339 thousand km roads completed benefiting about 81,600 habitations.

Asian Development Bank (ADB) assistance of USD 1195 million for Assam, Chattisgarh, Madhya Pradesh, Orissa and West Bengal.

Over ₹ 97 thousand crores (USD 18.9 billion) released to the states and an expenditure of over ₹ 88 thousands crores incurred.

World Bank Assistance of USD 400 million in RRP-I for Himachal Pradesh, Jharkand, Rajasthan and Uttar Pradesh and USD 1500 million in RRP-II for Himachal Pradesh, Jharkhand Meghalaya, Punjab, Rajasthan, Uttar Pradesh and Uttarakhand.

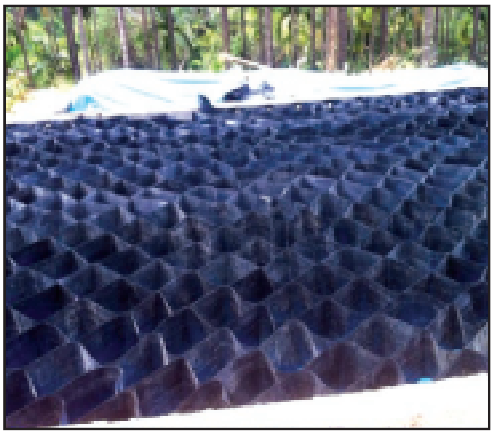
Over 22,000 engineers and personnel provided training for capacity development under the technical assistance programme of World Bank/NRRDA.

From January 2007 to December 2001, about 21,000 inspections carried out by independent National Quality Monitors.

The impact of PMGSY roads is clearly visible on the ground through better prices for agricultural produce, more employment opportunities, better access to health and educational facilities, marked access for rural households of quality consumer durables etc.

Pradhan Mantri Gram Sadak Yojana

R&D Initiatives taken up under PMGSY as Technology Demonstration/ Pilot Projects



Rural Roads Pavement Performance Study (RRPPS) has been completed on more than 200 road works, with the help of 15 PTAs/STAs.

9 road works using Jute Geo Textiles have been completed in Assam, Chhattisgarh, Madhya Pradesh, Orissa, West Bengal.

Cold Mix Technology being implemented in the State of Assam on 500 km road length.

28 road works taken up in Karnataka using Roller Compacted Concrete Pavement (RCCP) with Fly Ash, RCCP and Cement Concrete Pavement.

24 road works taken up in Karnataka using Gravel with Slag, Gravel Base, Cell Filled concrete, PQC, RBI -81, Lime Stabilization and Coir Technology.

41 road works in Karnataka using Jute Geo Textiles/ Coir Technology recently recommended.

4 road works taken up using CONSOLID 444 organic Chemical and SOLIDRY Powder in Gujarat.

1 road work taken up in Bihar using Silicon Aggregates.

1 road work taken up in West Bengal using Double Wall Corrugated High Density Polyethylene (DWHDP) Piping System

3 road works using Fly Ash, Steel Slag and Self Compacting Concrete have been completed in Maharashtra.

3 road works using SOILTECK MK-III polymer based Soil Stabilization technique recently sanctioned for Chhattisgarh.

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