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A Cost Effective Solution for Repair and Resurfacing of Distressed Asphalt Pavement by Coating of Ultra-Thin Whitetopping

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Abstract— Fly ash, a waste derived from coal burning in thermal power plants is bounteous in India causing severe health, environment and dumping problems. Now days, it is estimated that about 150 million tons of fly ash are being produced from various thermal power plants in India. Utilization of fly ash in bulk quantities, ways and means is being discovered all over the world to use it for the construction of embankments and pavements. This way the fly ash concrete are made a 'greener' building material and the discarded natural wastes can be re-utilized, avoiding otherwise wasteful landfill and harmful open incineration. To make value added concrete for development of sustainable infrastructure there is a great need to study the technical details concerned with various industrial wastes in concrete and to reduce environmental hazards. The significant increase in the number of automobiles observed in the recent years has created a need not only for the construction of new highways but also for the maintenance and rehabilitation of existing highway networks. Pavements are prone to damage due to the repeated wheel loads as well as temperature and other environmental effects. Ultra-thin white topping (UTWT) / thin white topping (TWT) is a technique which involves placement of a thinner (than normal) thickness ranging from 2 to 4 /4 to8 inches with closely spaced joints and bonded to an existing asphalt pavement. The application of UTWT/TWT has been targeted to rehabilitate deteriorated asphalt pavements with fatigue and/or rutting distress. However the actual depth of UTWT/TWT depends on the grade of concrete used, intensity of traffic, thickness of existing asphalt pavement after milling etc. So our study is concerned with eco-efficient utilization of Fly Ash (F-class) as partial replacement of cement in concrete. The aim of the present study is to investigate the low cost UTWT/TWT made of fly ash (F-class). The fly ash (F-class) was replaced within the range of 10-40% by weight of cement. In the present study, 5 different mixes of fly ash concretes are tested for parameters like: compressive strength, flexural strength, modulus of elasticity and cost.

Keywords- Fly Ash (F-Class), Asphalt Pavements, Ultra-Thin White Topping, Thin White Topping, Maintenance, Concrete

I. 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. This will require huge quantities of pavement construction materials. It has been observed that it would be economical to use industrial wastes in the construction of low cost roads. The quantities of wastes accumulating throughout the world are causing disposal problems that are both financially and environmentally expensive. One effective method to reduce some portion of the waste disposal problem is by recycling and utilizing these materials in the construction of highways without compromise their quality and performance. India produces a huge amount of waste materials as byproducts from different sectors like industrial, construction, agriculture, etc. These waste materials if not deposited safely it may be hazardous. A large quantity of waste material is dumped on land filling site, which if investigated properly can be utilized in the road construction sector. The utilization of these waste materials can be an economical and eco-friendly alternative in nearby areas for UTWT/TWT construction.

Ultra-thin white topping/ thin white topping is a relatively new rehabilitation technology applying a 50 to 100 mm (2- to 4-in)/ 100 to 200 mm (4- to 8-in) thick concrete overlay on top of existing asphalt pavement. UTWT/TWT i.e. laying of concrete over bituminous pavement with closer joint spacing, the details of which are given on IRC: SP 76:2008. UTWT/TWT can be designed for low-speed, low volume traffic areas such as street intersections, aviation taxiways and runways, bus stops and toll booths. For long term performance, the overlay must bond to the underlying asphalt so that the two layers respond in a monolithic manner, thereby reducing load-related stress.

Fly ash a finally divided mineral residue of burning of coal exhibits excellent. Geotechnical as well as Pozzolana properties that make it very suitable for all construction activities were including roads, embankments and renovation of low lying regions. Fly ash based construction materials are becoming favorite of the construction industry, being durable, economical, eco-friendly, easy to use and of consistent quality. Its effective use in concrete as partial replacement of cement will lead to reduce its disposal problems and also to enhance properties of concrete. Fly ash also holds potential to improve the socio-economic status for the development of rural areas in India.

II. EXPERIMENTAL WORK

A. Chemical Properties of Ordinary Portland Cement (OPC) and Fly Ash (F-Class):

It is Chemical Properties of Ordinary Portland Cement (OPC) and F-Class Fly Ash as listed in Table 1:

TABLE 1 CHEMICAL PROPERTIES OF ORDINARY PORTLAND CEMENT (OPC) AND FLY ASH (F-CLASS)

Chemical Properties	Percentage By Mass	
	Ordinary Portland Cement (OPC)	Fly Ash (Class-F)
Silicon Dioxide (SiO_2)	21.77%	62.22%
Calcium Oxide (CaO)	57.02%	5.30%
Magnesium Oxide (MgO)	2.71%	6.09%
Sulphur Trioxide (SO_3)	2.41%	3.00%
Aluminium Oxide (Al_2O_3)	2.59%	7.63%
Ferric Oxide (Fe_2O_3)	0.65%	0.13%
Loss on Ignition (L.o.I.)	2.82%	9.98%

Source: Tested by "GEO TEST HOUSE" Vadodara, Gujarat

B. Characterization of cement:

The most common cement used is an Ordinary Portland Cement (OPC). The Ordinary Portland Cement of 53 grades is conforming to IS: 8112- 1989 is being used. Specific gravity, consistency tests, setting time tests, compressive strengths, etc. are conducted on cement. The results are tabulated in table 2.

TABLE 2 PROPERTIES OF ORDINARY PORTLAND CEMENT (OPC)

Sr. No.	Physical Properties of Cement	Result	Requirements as per IS:8112-1989
1	Specific gravity	3.15	3.10-3.15
2	Standard consistency (%)	28%	30-35

3	Initial setting time (hours, min)	35 min	30 minimum
4	Final setting time (hours, min)	178 min	600 maximum
5	Compressive strength- 7 days	38.49 N/mm^2	43 N/mm^2
6	Compressive strength- 28 days	52.31 N/mm^2	53 N/mm^2

Source: Tested by "GEO TEST HOUSE" Vadodara, Gujarat

C. *Cement fly ash Mix Proportions:*

A mix M40 grade was designed as per IS 10262:2009 and the same was used to prepare the test samples. The design mix proportion is shown in Table 3.

TABLE 3 CONCRETE DESIGN MIX PROPORTIONS FOR M40

Sr. No.	Concrete Mix	Water/Cement Ratio	Cement (Kg)	Fine Aggregate (Kg)	Course Aggregate (Kg)	Cement Replacement By Fly Ash (Class-F) (Kg)
1.	A1-M40	0.39	1	1.18	2.58	-
2.	B1-M40	0.39	0.90	1.18	2.58	0.10
3.	B2-M40	0.39	0.80	1.18	2.58	0.20
4.	B3-M40	0.39	0.70	1.18	2.58	0.30
5.	B4-M40	0.39	0.60	1.18	2.58	0.40

III. EXPERIMENTAL RESULTS

Above 5 different concrete samples were used to find the important properties like compressive strength, flexural strength and modulus of elasticity. To make the study from an economic point of view, the cost of each mix was also worked out from the present market rates. The results for these properties are given in Table 4, 5 & 6.

TABLE 4 AVERAGE COMPRESSIVE STRENGTH FOR CUBES OF (150X150X150) mm. (N/mm²) AT 7, 14, 28 DAYS FOR M40

Concrete Mix	Average Compressive Strength (N/mm^2)		
	7 Days	14 Days	28 Days
A1-M40	32.72	43.27	48.42
B1-M40	27.83	40.93	46.19
B2-M40	24.85	34.29	42.73
B3-M40	21.47	27.29	33.71
B4-M40	17.89	22.87	26.48

Source: Concrete Technology Lab, BVM Engineering College

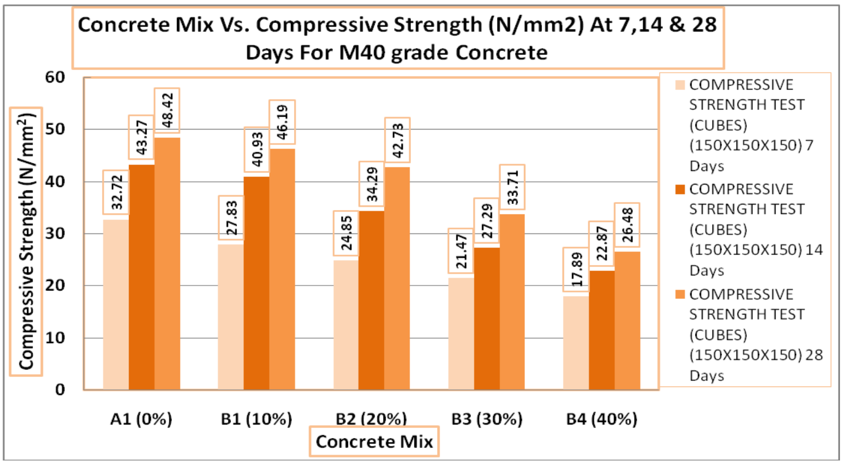

Figure: 1 Concrete Mix v/s Average Compressive Strength (N/mm²) at 7, 14, 28 Days for M40

TABLE 5 AVERAGE FLEXURAL STRENGTH FOR BEAMS OF (100X100X500) mm. (N/mm²) AT 7, 14, 28 DAYS FOR M40

Concrete Mix	Average Flexural Strength (N/mm^2)		
	7 Days	14 Days	28 Days
A1-M40	2.74	3.79	4.88
B1-M40	2.51	3.57	4.73
B2-M40	2.25	3.28	4.53
B3-M40	1.73	2.61	3.87
B4-M40	1.47	2.26	3.33

Source: Concrete Technology Lab, BVM Engineering College

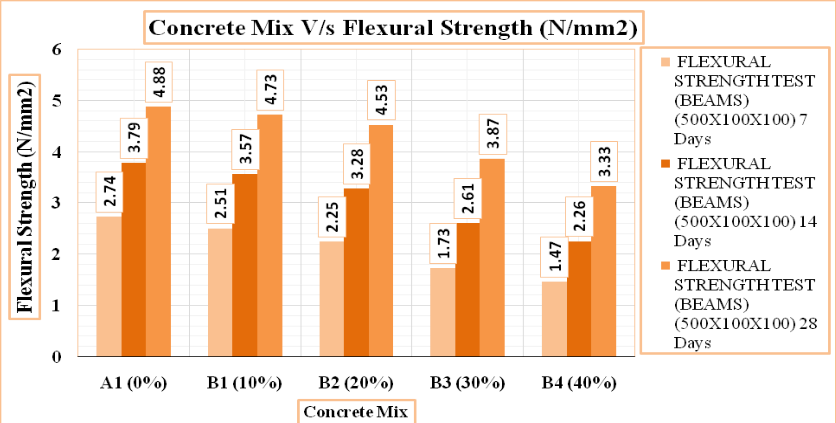

Figure: 2 Concrete Mix v/s Average Flexural Strength (N/mm²) at 7, 14, 28 Days for M40

TABLE 6 MODULUS OF ELASTICITY FOR CYLINDER (150 mmX300 mm DIA.) (N/mm²) AT 28 DAYS FOR M40

Concrete Mix	Modulus of Elasticity (N/mm^2) 28 Days
A1-M40	34583
B1-M40	38500
B2-M40	36167

B3-M40	30667
B4-M40	28500

Source: Concrete Technology Lab, BVM Engineering College

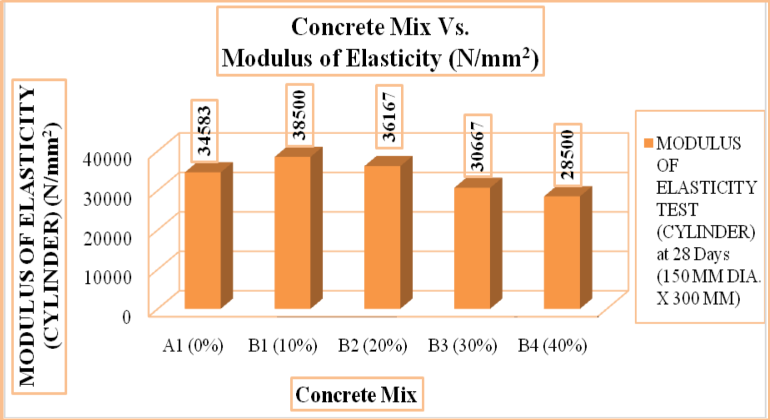

Figure: 3 Concrete Mix v/s Average Modulus of Elasticity (150X300 dia.) (N/mm²) at 28 Days for M40

A. *DESIGN OF A UTWT/TWT PAVEMENT AS PER IRC:SP:76-2008 / IRC:58-2002*

A UTWT/TWT is to be designed for a distressed asphalt pavement in Gujarat State having a traffic volume of 500 vehicles per day consisting vehicles, like, agricultural tractors/trailers, light goods vehicles, heavy trucks, buses, animal drawn vehicles, motorized two-wheels and cycles. The soil has a soaked CBR value of 2%.

TABLE 7 Design Parameters: Sample B1

Traffic Volume (A)	= 500 CVPD (Assume)
Concrete Grade (f_c)	= 40 N/mm^2
Characteristic Compressive Cube Strength	= 46.19 N/mm^2 at 28 Days Actual Compressive Strength
Flexural Strength (f_f)	= 4.73 N/mm^2 [47.3 kg/cm^2]
Soaked CBR Value (%)	= 0.02 (2%)
Modulus of Subgrade Reaction (k) (Table-1,Page-4)	=21 N/mm^3
Subgrade Modulus	=10 kg/cm^3
Elastic modulus of Concrete (E_c)	= 38500 N/mm^2
Poisson's ratio (µ)	= 0.15
Coefficient of thermal coefficient of concrete (α)	= 0.00001/°C
Traffic Growth rate , r	=0.075
Wheel Load (P)	= 30 Kn
Tyre pressure (q)	= 0.5 N/mm^2 [5 kg/cm^2]
Spacing of Contraction Joints (L)	= 1m [1000 mm]
Width of Slab (W)	= 1m [1000 mm]
Design life (n)	=20 Years
Load Safety Factor	=1.0

Table 8 Design from Fatigue Consideration using Programme IITRIGID for Single Axles

Axle Load class, Tons	Load In, Tonnes	Percentage of axle Loads, P	Expected Repetition
15-17	16	0.7	13830

13-15	14	1.0	19758
11-13	12	34.3	677691
9-11	10	33.0	652006
Less than 9	Less Than 10	28.2	557169
Total		97.2	1920454.4

Table 9 Design from Fatigue Consideration using Programme IITRIGID for Tandem Axles

Axle Load class, Tons	Load In, Tonnes	Percentage of axle Loads, P	Expected Repetition
26-30	28	0.2	3952
22-26	24	0.2	3952
18-22	20	0.3	5927
14-18	16	0.1	1976
Less than 14	Less than 16	2.0	39516
Total		2.8	55322

Trial Thickness for Slab, h = 170mm

Table 10 Stress Ratio at Different Axle Loads under the Category of Single Axles

Axle load(AL) ,tonnes	Stress, Kg/ cm^2 from IITREIGID Program X .65	Stress ratio (σ/f_{cr})	Expected repetitions, n	Fatigue life, N X 0.75	Fatigue life consumed (n/N)
Single axle					
16	27.9	0.59	13830	40591.03	0.34
14	25.1	0.53	19758	231004.57	0.09
12	22.5	0.47	677691	3512747	0.19
10	19.0	0.40	652006	Infinite	0.00
Less than 10			557169	Infinite	0.00
Total			1920454		0.43

Table 11 Stress Ratio at Different Axle Loads under the Category of Tandem Axles

Tandem axle					
28	19.8	0.42	3952	Infinite	0.00
24	17.4	0.37	3952	Infinite	0.00
20	15.5	0.33	5927	Infinite	0.00
16	12.6	0.27	1976	Infinite	0.00
Less than 16			39516	Infinite	0.00
			55322		0.00
			Total		0.43
The cumulative fatigue life consumed being less than 1, so the design is safe from fatigue considerations.					

Design of TWT using Westergaard Equation and Warping Stresses as per IRC: SP: 76: 2008 and IRC: 58-2002

1. **Check for Temperature Stresses:**

Temperature Stress (σte):

The temperature differential (Δt) for Gujarat for a slab thickness of 170 mm is 12.74˚C.

The Radius of Relative Stiffness, l= $\sqrt[4]{\frac{E\ h^3}{12\ (1-\ \mu^2)\ k}}$

Hence, l = 93.61 cm.

L / l = 100 / 93.61= 1.07

W / l = 100 / 93.61= 1.07

Both values are same, if not then adopt greater one.

Bradbury's Coefficient, C = 0.004 (from figure 1, pg. 9)

[Value of C can be ascertained directly from Bradbury's chart against values of L/l and W/l]

Temperature Stress in edge region, σte = (E α Δt)/2 C

Hence, σte = 0.98 kg/cm²

2. **Edge Load Stress (σle):**

From Page: 12, Edge Load Stress,

σte = 0.529 P/h^2 (1+0.54μ)[4log10 (l/b)+ log(b)-0.4048]

Where,

b = Radius of equivalent distribution of pressure,

b = a, if (a/h >= 1.724);

b = $(1.6a^2 + h^2)^{0.5}$- 0.675 h, if (a/h < 1.724),

For slab thickness of 170mm;

Edge Load Stress, σte, is **3.29 N/mm^2 (3.29 MPa).**

Reduce Load Stress = Load Stress in Critical Edge Region*0.65

= 3.29*0.65

=2.143 N/mm^2

Total Stress = Edge Load Stress + Temperature Stress

= 2.14 + 0.98

= 3.12 N/mm^2,

This is less than the allowable flexural strength of 4.73 N/mm^2.

Hence, assumed thickness of slab = 170mm, is OK.

The calculations presented above are sample calculations. Similar calculations are done using various values of Flexural and Compressive Strength & Modulus of Elasticity of concrete.

IV.ECONOMIC ANALYSIS

TABLE- 12 COST OF MATERIALS

Sr. No.	Materials	Cost (Rs./kg)
1.	Cement	6.4
2.	Fly Ash	0.46
3.	Fine Aggregate	0.60
4.	Coarse aggregate	0.65

TABLE-13 MATERIALS FOR DESIGNED M40 CONCRETE

Concrete Mix	% Reduction in Cement	Materials				Total cost (Rs./m3)	% Change in Cost
		Cement	Fine Aggregate	Coarse aggregate	Fly Ash		
A1-M40	0	476.92	563.68	1235.13	0	4193.33	0
B1-M40	10	429.3	563.68	1235.13	47.7	3910.50	(-) 6.74
B2-M40	20	381.6	563.68	1235.13	95.4	3627.16	(-) 13.50
B3-M40	30	333.9	563.68	1235.13	143.1	3343.93	(-) 20.25
B4-M40	40	286.2	563.68	1235.13	190.8	3060.59	(-) 27.01

TABLE 14 RELATIVE COST OF SLAB FOR M40

Concrete Mix	Slab Thickness (cm)	Cost of 1m x 1m Slab (Rs.)	Relative Cost (%)
A1-M40	17	712.86	100.00
B1-M40	17	664.78	93.25
B2-M40	18	652.88	91.58
B3-M40	19	635.34	89.13
B4-M40	20	612.12	85.87

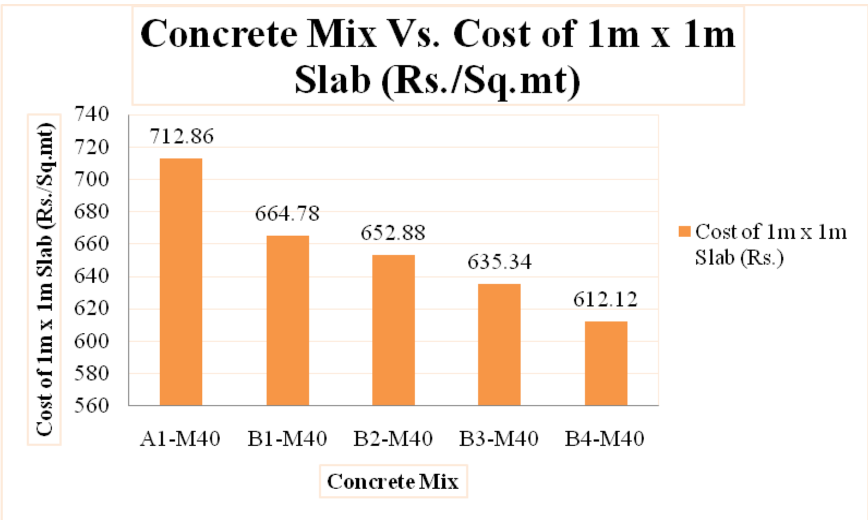

Figure: 4 Concrete Mix v/s Cost of 1m x 1m Slab (Rs./Sq.mt)

CONCLUSIONS

Based on limited experimental investigations concerning the compressive strength, flexural strength & modulus of elasticity test of concrete (M40 Grade) for rigid pavement, the following observations are made in the ray of the objectives of the study:

(a) Use of fly ash in UTWT/TWT can save the thermal industry disposal costs and produce a greener' concrete for low cost UTWT/TWT pavements.
(b) This research concludes that fly ash (Class-F) can be an innovative Supplementary Cementations Material useful for development of low cost UTWT/TWT pavements.
(c) India should aggressively identify projects that can use large amounts of fly ash in road construction so that harmonizing environment and ecological sustainability can be developed. Use of fly ash in road construction works will result in the less depletion of naturally available stone metal, gravel, sand and soil; and will save cement, which is the costliest ingredient will lead to reduction in construction cost. With adequate knowledge on performance of fly ash based road pavements, a huge demand can be expected from the road sector to use fly ash for construction purposes, but judicious decisions are to be taken by engineers, for development of low cost UTWT/TWT pavements.
(d) This research study concludes that there is a great scope for eco-efficient utilization of Fly Ash (Class-F) for sustainable development of Indian Road Network.
(e) According to IRC standards, there is a feasible use of Fly Ash (Class-F) up to 20% of partial replacement of Cement.

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