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A REVIEW OF USING THIN WHITE TOPPING OVERLAYS FOR REHABILITATION OF ASPHALT PAVEMENTS

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Abstract—*In India, majority of roads are made of asphalt which gets deteriorated over time either due to heavy truck loadings or due to environmental and temperature effects. These roads are not only prone to early deterioration but also have higher maintenance costs as compared to cement concrete pavements. Asphalt overlays, and sometimes cement concrete overlays, are commonly used as traditional methods for repairs of distresses. Thin whitetopping can be an effective and sustainable alternative rehabilitation technique for deteriorated asphalt pavements when rutting or surface cracking is a major problem. Thin whitetopping is a plain cement concrete overlay laid over rutted asphalt surface with the formation of bond between the underlying asphalt layer and overlying PCC layer. It is more durable, economical and environmentally and socially beneficial than asphalt overlays.*

In this paper, a review concerning the advantages and benefits of thin whitetopping over asphalt overlays is done and a comparison is made between thin whitetopping and asphalt pavements, to be used as rehabilitation technique for rutted asphalt pavements, considering sustainability as the main aspect. Various factors such as design life, life cycle cost and other environmental effects of both are considered and discussed. Finally it is concluded that using thin whitetopping as a rehabilitation technique proves to be more economical when overall life cycle cost is considered, more durable and have many environmental and social benefits thus making it more sustainable than asphalt overlays.

Keywords: *Asphalt, Overlay, Rehabilitation, Sustainability, Whitetopping*

1. INTRODUCTION

Road building needs huge investments not only for construction of new infrastructure but also for the repair and maintenance of the old ones. In case of developing countries, like India, there is a shortage of funds required for new infrastructure projects- both for construction and more significantly for their maintenance and repairs. Most of the existing pavements in the country are flexible in nature and have a bituminous wearing course. These bituminous pavements get deteriorated with time having deficiencies like rutting, cracking, potholes etc. The increasing loads of trucks and tyre pressures on asphalt pavements in recent years have pushed the demand on the performance of these pavements to a higher level. Many asphalt pavements have experienced rutting while many others have experienced longitudinal cracking.

One of the possible alternative rehabilitation solutions to this problem is the use of whitetopping which is a Portland Cement Concrete (PCC) overlay on an existing bituminous pavement. The principal purpose of this technique is either to restore the functional capacity or to increase the load carrying capacity of the road or both, of the existing pavement. In the process of achieving this objective,

whitetopping overlays also restore the ride-ability of the existing asphalt pavements suffering from ruts and deformations, in addition to rectifying other defects such as loss of texture. Whitetopping being stronger than asphalt overlay is more resistant to rutting and surface initiated cracking and thus this technique pose potential economical and technical benefits.

The present paper discusses various advantages of using thin whitetopping as an alternative technique for rehabilitation of rutted asphalt pavements. Various factors such as design life, heat island effects, life cycle costs, embodied primary energy, truck fuel savings, recyclability, solar reflectance and other environmental effects are considered and reviewed for both thin whitetopping and asphalt pavements. Finally, it is concluded that using thin whitetopping instead of asphalt overlays proves to be more economical, durable and thus more sustainable.

2. OVERVIEW OF WHITETOPPING

Whitetopping is a PCC overlay constructed on top of asphalt pavements as rehabilitation or strengthening alternative. It is commonly applied where rutting of asphalt pavements is a recurring problem. Concrete overlays offers potential for extended service life, increased structural capacity, reduced maintenance requirements and lower life cycle costs when compared with asphalt overlays.

Whitetopping can be classified into three types based on the degree of bonding between the underlying asphalt layer and overlying PCC layer. The three types of interfaces are as follows and shown in Fig. 1:

i.)Bonded interface ii.)Unbonded interface
iii.)Partial bonded interface

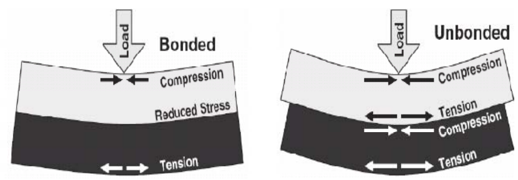

Fig. 1: Bonded Vs. Unbonded behavior (Rasmussen et al. 2004)

Based on the types of interface provided and the thickness of overlay, whitetopping can be classified as follows:

i) **Conventional White topping** – It consists of PCC overlay of thickness 200 mm or more, which is designed & constructed without consideration of any bond between existing overlay and underlying bituminous layer (without assuming any composite action).

ii) **Thin White topping (TWT)** – The thickness of PCC overlay is between 100 – 200 mm. It is designed either considering bond between overlay & underlying bituminous layer or without consideration of bond. High strength concrete (M 40 or higher) is normally used to take care of flexure requirement. Joints are at shorter spacing of 0.6 to 1.25 m.

iii) Ultra-Thin White topping (UTWT) – It has PCC overlay of less than 100 mm. bonding between overlay and underlying bituminous layer, is mandatory. To ensure this, the existing layer of bitumen is either milled (to a depth of 25 mm) or surface scrapped (with a non-impact scrapper) or gently chiseled. Joints are provided at a spacing of 0.6 to 1.25 m.

3. HISTORY OF WHITETOPPING

Concrete overlays are been used to rehabilitate asphalt pavements since 1918 in USA, the first project being constructed in Terre Haute, Indiana (Hutchinson, 1982). From then till 1992, approximately 200 whitetopping projects had been documented. Since 1992, the ACPA tracked documented more than 300 projects during this 10 year period.

Whitetopping in its various forms have been used in USA and Europe on airports, inter-state roads, primary and secondary highways, local roads, streets and parking lots to improve the performance, durability and riding quality of asphalt pavement surfaces. There has been a renewed interest in whitetopping, particularly, in thin whitetopping and ultrathin whitetopping during the last decade possibly due to several successful high profile projects in USA and Europe.

Thin and ultrathin whitetopping overlay projects has been started in India in 2003. Table (1) below shows various thin whitetopping projects that have been constructed in India till 2009.

Table 1: Projects of TWT in India

Year	Location	Thickness(mm)
2003	Pune (In front of P.M.C Office)	125
2004	New Delhi (CRRI Campus road)	40-75
2006	New Delhi (Moolchand nad Prembari underpass)	125
2006	Ghaziabad (Campune road of HRD Centre)	50
2006	New Delhi (NDMC Office Campus Road at Parliament Street)	100
2006	New Delhi (Meethapur, Badarpur)	125
2007	Mumbai (Mahul Road)	100
2008	Thane (In Goathan area)	125
2009	Pune (Dhanukar Colony, Kothrud)	125

4. MECHANISM OF THIN WHITETOPPING

Thin Whitetopping overlays, as a rehabilitation technique, provide a unique pavement structure which is fundamentally different from the conventional or bituminous pavements.

Here, the TWT are designed considering a sound bond between the overlying concrete pavement and underlying asphalt pavement which is achieved by milling the top asphalt surface to a depth of 25mm-50mm. The bond between concrete and asphalt layer interface creates the necessary composite section which lowers the neutral axis and reduces the load stresses. Due to lowering of neutral axis, more area of concrete slab comes under compression region and the underlying asphalt pavement bears the tension. As concrete is good in compression, hence, lesser thickness of the overlying PCC pavement is required. In case of thin whitetopping, a reduction of 35% in load induced stresses is considered as per IRC: SP: 76-2008 while determining the stresses and thickness of concrete slab.

The effect of neutral axis is shown in Fig. (2) below:

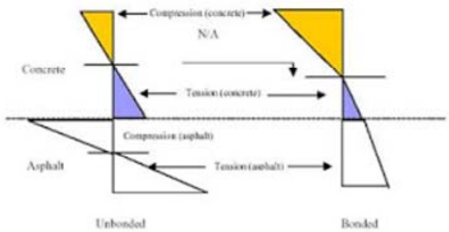

Fig. 2: Stress distribution in bonded and unbounded pavement layers

5. SALIENT FEATURES OF THIN WHITETOPPING

The development of an effective bond between the plain cement concrete overlay and existing asphalt pavement is critical for the performance of thin whitetopping because due to the formation of bond between these layers, the total stresses gets reduced and thus a part of traffic load is being relied upon.

- For the achievement of bond between the concrete and asphalt layer, extensive surface preparation is requiredwhich can be achieved either by chiselling or by milling the asphalt surface to a depth of 25mm-50mm.
- Shorter joint spacing, mostly square, with slab size ranging from 0.6m to 1.25m is provided to reduce the overall warping stresses. Use of shorter joint spacings also helps in reduction of load stresses during night hours.
- The minimum thickness of asphalt layer, after milling, as suggested by IRC: SP: 76-2008, is 75mm. But, if the subgrade conditions are good or the base course is cement treated one, thin whitetopping can be applied to a pavement having asphalt thickness of 50mm.

6. ADVANTAGES OF THIN WHITETOPPING OVER ASPHALT PAVEMENTS

1. Extended Design Life

Concrete pavements have always resulted in extended service life either used for new construction or for overlays. Several projects of whitetopping constructed in India and other countries have given satisfactory to excellent results when their design life is considered. Thin whitetopping, in certain areas have encountered minor cracks after long run but is more reliable as compared to asphalt pavements. Some of the examples of thin whitetopping are stated below:

In 1996, a TWT project was constructed in Minnessota on Lor Ray Drive, in North Mankato (Vandenbossche and Rettner 1999). The asphalt pavement was severely rutted and hence, whitetopping was laid over it. After 3.5 years and approximately 4.7 million ESALs, the pavement section was evaluated. No noticeable distresses or reflection cracks were found. Few corner cracks occurred but the riding quality of this section was excellent.(Vandenbossche and Fagerness 2002).

In May 2003, TWT was placed in Florida at Fernandina Beach Airport in Florida (Armaghani et al. 2005). The whitetoppings were 6 in. thick on the runway and 5 in. thick on taxiway laid over severely rutted asphalt pavements. Condition survey of this project was conducted in 2004 and the following points were concluded:

1. No cracking of the whitetopping was found except some corner chipping, which might have resulted from inadequate timing of joint sawing. The shoulder was in good condition with no sign of erosion and skid resistance was very high according to FDOT’s Runway Friction Tester results.

2. Stiffness of the pavement system resulting from whitetopping placement increased by an average of 300%, which indicated enhanced load-carrying capacity. Good bond between whitetopping and the AC layer was found from the falling weight deflectometer (FWD) testing.

2. Reduced Life Cycle Costs

A life cycle cost analysis considers the pavement’s initial cost, maintenance, and reconstruction costs during a specified lifetime. The placement or construction of thin whitetopping generally has a higher initial cost than asphalt overlays. Yet, concrete overlays generally have a longer useful service life and less maintenance costs during its life. Life cycle cost analysis shows that thin whitetopping overlay cost less than an equivalent asphalt overlay for the same lifetime.

The initial cost for construction of thin whitetopping is nearly 1.5-2 times the cost for construction of asphalt overlays. But asphalt overlays needs periodic maintenance whereas thin whitetopping, being a concrete pavement, does not require any periodic maintenance. Therefore, the cost of maintenance of asphalt overlays is much more as compared to thin whitetopping.

V.K Sinha, Satander Kumar and R.K Jain have represented whitetopping as a cost-effective rehabilitation alternative for preservation of asphalt pavements on long term basis in their research ”Whitetopping As a Rehabilitation Method: A Case Study of Budhel- Ghogha Road”. In this paper, design of 150mm thin whitetopping and 150mm bituminous macadam as asphalt overlays are done keeping all the constraints same. Finally, life cycle cost for both the designs is computed and it is observed that by using thin whitetopping as overlay instead of asphalt, there is a saving of nearly 20% of the total cost of asphalt overlay. Hence, thin whitetopping have a reduced overall cost as compared to asphalt overlays.

3. Reduced Maintenance and Repair

Thin whitetopping, being a cement concrete pavement structure, requires lesser maintenance as compared to asphalt pavements. As stated earlier, asphalt pavements are prone to early deterioration with distresses such as rutting, fatigue, surface cracking. Moreover, asphalt pavements are more effected by wheel loadings and other environmental effects. Concrete overlays are lesser prone to deterioration due to their rigid structure and slab action.

As per Indian Cement Review, asphalt roads require maintenance after every 2 to 4 years and resurfacing after every 8 to 10 years whereas concrete pavements require lesser maintenance and some minor repairs to joints and surface textures. Hence the maintenance cost of asphalt overlays is 8 to 10 times more than concrete overlays in smooth traffic flow over longer period.

4. Incorporation of Industrial Bi-Products

Portland cement can be replaced or supplemented with one or more industrial byproducts which are often referred to as supplementary cementitious materials (SCMs). The three most commonly used SCMs are fly ash, a byproduct of coal burning, slag cement or ground granulated blast furnace slag, a byproduct of iron production, and silica fume, a byproduct of silicon or ferrosilicon alloy manufacturing. SCMs are widely used with cement to enhance its properties. Two of the more common SCMs are slag and fly ash which are byproducts of steel manufacturing and thermal power generation respectively. Cement and concrete incorporating SCMs helps in reduction of CO_2 footprint, yet saving the environment by preventing these hazardous materials ending up in the landfill sites.

Using SCMs in concrete pavement has several environmental benefits. First, using waste industrial byproducts avoids the extra use of virgin materials needed for cement manufacturing. Additionally, beneficial utilization reduces the amount disposed in landfills. More importantly, however, are the greenhouse gas and energy reductions achievable by using SCMs to replace a portion of portland cement. CO_2 and energy savings are related to the percentage of SCM used in the concrete mixture design. Many state highway agencies allow up to 25% of portland cement to be replaced with fly ash and 50% to be replaced with slag cement; some states even allow higher SCM replacement levels.

A study (Marceau and VanGeem 2005) proved that, for a typical concrete pavement mixture, replacement of 50% of the portland cement with slag cement resulted in a 35% reduction in embodied primary energy and a 45% reduction in embodied greenhouse gas per cubic meter of concrete. This calculation includes all the energy utilized and emissions generated in mining, manufacturing and transporting concrete's constituent materials, as well as the manufacturing processes involved with producing concrete.

5. Heavy Truck Fuel Saving

Profile stability describes the ability of a pavement surface to resist deformation and deflection caused by sustained and repeated loading. Asphalt pavement is visco-elastic and therefore sensitive to both temperature and loading but concrete pavement have a rigid surface and does not deform under heavy vehicle loading and therefore deflects less. This not only makes concrete pavement less susceptible to the formation of heavy-vehicle wheel ruts and the associated increased hydroplaning potential, it also positively impacts vehicle fuel consumption.

Fuel consumption is partly a function of the degree to which a pavement deflects in response to the load applied as the wheels of heavy vehicles traverse the surface. The deflection absorbs some amount of the energy which could have been utilized to propel the vehicle forward.

Several studies to date suggest that the amount of deflection encountered by heavy-vehicle wheels on asphalt pavements is greater than deflection on concrete pavements as shown in Fig. 3. Thus, more energy and more fuel are required to move heavy vehicles on flexible pavements (Taylor Consulting 2002).

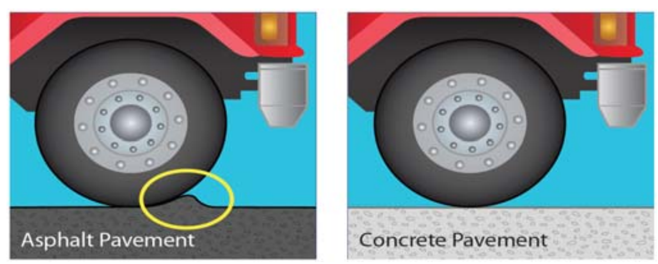

Fig. 3: Exaggerated depiction of a truck tire rolling on asphalt pavement (left) and concrete pavement (right)

National Research Council of Canada (NRC) studies comparing the fuel consumption of heavy vehicles operating on different types of pavement surfaces concluded that there is a savings ranging from of 0.8 to 6.9 percent when operating on concrete pavement compared to asphalt pavement.

- The hypothesis is based on heavy vehicles causing greater deflection on flexible pavements than on rigid pavements. This increased deflection of the pavement absorbs part of the vehicles rolling energy that would otherwise be available to propel the vehicle.
- Several variables which were included in the analysis are pavement type, pavement roughness, vehicle type, different loading conditions, different speeds, different seasons (spring, summer day, summer night, fall and winter), pavement grade and wind speed.

- Fuel savings are based on comparing smooth asphalt pavements versus smooth concrete pavements.
- Phase II study demonstrated statistically significant fuel savings for tractor tanker semitrailers (5axle) vehicles traveling on smooth roads from 4.1% to 6.9% depending on operating speed.
- Phase III study demonstrated statistically significant fuel savings for tractor van semitrailers (6axle) vehicles traveling on smooth roads from 0.8% to 3.9% depending on operating speed. The summer night data was excluded from the analysis, even though it was in concrete's favor, due to it not being statistically significant.

6. Lower Construction Fuel Demand

The construction of highway pavements requires a lot of energy, mostly in form of diesel, for the production of paving materials, the transportation of these materials to the site, and their actual placement.

The Federal Highway Administration (FHWA) reports for various elements of construction, including highway paving, on fuel usage in its Technical Advisory T 5080.3 on Price Adjustment Contract Provisions (FHWA 1980) which shows that the fuel usage factor for asphalt pavements is 12 litres per metric ton, and for concrete pavements is 4.9 litres per cubic meter. However, as these fuel usage factors are reported in different units, it is somewhat difficult to make a direct comparison (FHWA 1980).

Hence comparison of fuel usage is provided in Table 2 which converts these construction fuel usage factors to fuel required per mile of roadway constructed for asphalt and concrete. Though equivalently designed concrete pavement thickness is typically between two and three inches thinner than an asphalt pavement designed for the same scenario, here it is assumes that the pavements have the same thickness.

The table 2 shows that the amount of fuel used per lane-mile (lane-km) of concrete roadway constructed is less than one-fifth of the fuel used to construct the same lane-mile (lane-km) of asphalt.

In addition to the obvious economic benefits, there are environmental advantages also. The savings in diesel fuel eliminates the emission of approximately 13.3 million tons (12.1 million metric tons) of CO_2 into the atmosphere each year.

Table 2: Construction fuel demand for asphalt versus concrete pavement

Pavement type	Thickness	Construction Fuel Demand
Asphalt	10 in. (250 mm)	10,718 gal (40,572 l)
Concrete	10 in. (250 mm)	1,916 gal (7,252 l)

Assumptions: Asphalt density = 140 lb/yd³ (83 kg/m³). Fuel usage factors: Asphalt – 2.90 gal/ton (12 l/metric ton), Concrete – 0.98 gal/cy (4.9 l/m³) from FHWA T 5080.3, Attachment 1.

7. Other Environmental Effects

a) Embodied Primary Energy

Embodied primary energy is a measure of all energy use associated with the production, delivery, and maintenance of a facility over a predetermined time period. It includes both feedstock energy (the gross combustion heat value of any fossil hydrocarbon that is part of the pavement, but is not used as an energy source; e.g., bitumen) as well as primary energy (fossil fuel required by system processes including upstream energy use).

A recent study of Life cycle assessment research conducted by the Athena Institute presents embodied primary energy and global warming estimates for the construction and maintenance of equivalent concrete and asphalt pavement structures for several different road types in various geographic regions in Canada (Athena Institute 2006). The study period was 50 years that takes into account original road construction and all maintenance and rehabilitation activities for both pavement alternatives. It shows that the energy use footprint for concrete pavement structures is substantially lower than asphalt pavement structures.

The results show that asphalt pavements require two to five times more energy than equivalent concrete pavement alternatives.

b) Reduced Urban Heat Island Effect

Heat island effect describes the increase of ambient temperatures in cities during warmer months due to the absorption of heat from the sun. Asphalt pavement being darker absorbs huge amount of heat energy and thus have an albedo of 0.04 (Akbari 2000).

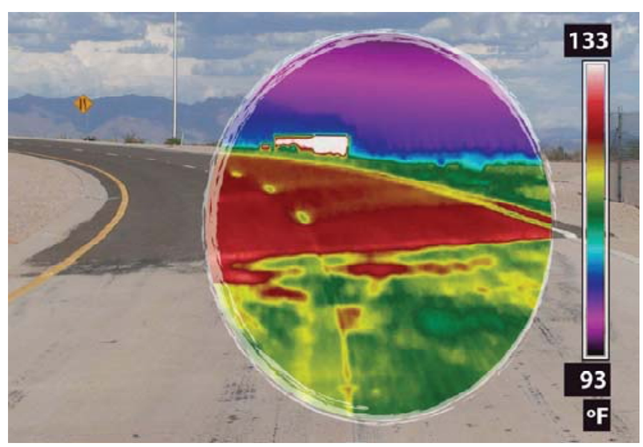

Fig. 4: Thermal image of a pavement in Mesa, Arizona (note the temperature difference between the concrete pavement (foreground) and the asphalt pavement (background))

As paved surfaces consists of 30-40% of urban areas, these urban areas are 2-4◦ C warmer as compared to surrounding rural areas thus creating heat island effects. Concrete pavement provides reflective surfaces that minimize the urban heat island effect because it is lighter in color with higher solar reflectance (albedo), also saving energy by reducing the demand for air conditioning and reducing power plant emissions. Cooler air can also reduce air pollution by slowing the chemical reactions that produce smog. Dark surfaces like asphalt pavement have several consequences associated with them. One such consequence is elevated temperature of storm water runoff. Hotter runoff can be detrimental to aquatic life and ecosystems. Hence, concrete pavements are more suited to prevent heat island effect. The effect of rise in temperature of pavements is shown in Fig. 4;

c) Superior Solar Reflectance

Concrete surfaces readily reflect light due to lesser albedo, and are advantageous as they improve both pedestrian and vehicular safety by enhancing night time visibility on and along concrete roadways and also reduces the amount of energy needed for artificial roadway illumination during the night.

Lighting fixtures are important elements of most urban highway facilities because enhancing the night time visibility helps in improving traffic safety. A report comparing the environmental impacts of concrete pavements to asphalt pavements indicates that asphalt pavements require more lights per unit length to achieve the same illumination as concrete pavements (Gajda and VanGeem 1997). The results suggest cost savings of as much as 31% in initial energy and maintenance costs for lighting concrete pavements versus lighting asphalt pavements. Similar results are shown in Fig. 5, where energy costs required to illuminate an asphalt roadway are estimated to exceed the costs of illuminating a concrete roadway by 33%.

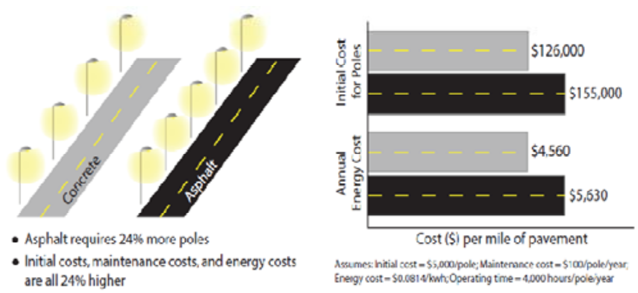

Fig. 5: Lightings on Bituminous and Concrete Surface

d) Other Benefits of Thin Whitetopping

There are several other effects which help in proving thin whitetopping concrete overlays more sustainable than asphalt overlays. These are:

- Renewability and recycling properties of concrete
- Fire resistance property of concrete
- Locally produced
- Helps in smog reduction
- Minimum waste production
- Quieter surface texture, thus reducing noise pollution

7. CONCLUSIONS

Thin whitetopping overlays are considered more environmentally and economically sustainable as compared to asphalt pavements.

These concrete overlays do not require maintenance or repair for a longer duration and, therefore, consume fewer raw materials over time. Energy savings also are realized, since rehabilitation and reconstruction efforts consume energy. Even more importantly, congestion is reduced by using long-lasting concrete overlays because of less frequent construction zones that impede traffic flow. Construction of thin whitetopping do not produce any waste material, rather it utilizes the underlying asphalt layer to form a composite structure, thus reducing overall thickness of the pavement and making the project economical. Ultimately, all of these benefits add up to greater long-term economic and social benefits to the public.

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