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White Topping: A Review of Design and Construction Procedures

Abdulazeez Lawal[1]

[1]*Research Assistant, Institute of Transportation at Iowa State University*

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Abstract – *World urban population growth in the 21st century has been directly linked to exponential traffic growth and subsequent excessive strains on major infrastructure systems. With the continually rising movement of people and freights, highway systems increased deterioration has been a major consequence. To rise up to this challenge, transportation agencies have explored different pavement maintenance and rehabilitation techniques across different cost and timeline spectrums – with white topping representing a viable option. Thus, this paper discusses white topping as a pavement rehabilitation technique, and synthesizes the different design and construction procedures usually explored. It also looks at some recommended best practices adopted by some pioneering departments of transportation within the United States.*

Key Words: White topping, Pavement management, Overlays, Rehabilitation, Hot Mix Asphalt, Portland Concrete Cement.

1. INTRODUCTION

The 21st century has been marked with a tremendous increase in the urban population of the world. More specifically, between the years of 1950 and 2000, there has been a 17% rise in the population of urban dwellers. Europe, North America, Latin America and the Caribbean continue to enjoy its fair share of the surge, with about 75% of their populace residing in cities [1] The resulting development has put an enormous strain on basic infrastructure and service in the cities [13]. The effect of this is that a more sophisticated or enhanced infrastructure system is required to be put in place to effectively address the needs of the increased population [1]

One of the direct spin-offs of the trend is the growth of traffic. The impact of traffic growth as a result of the increasing population can be measured by the quality of road networks. The nation's highway is at a great risk of suffering from deterioration even before the design life is met, as a result of the increasing loads [15]. This thus mean that as they age and show some signs of defect, different types of rehabilitation solutions are eventually required to restore the functional requirements of the roads for users [2]

According to FHWA (1997), it is sine qua non to conduct a pavement condition survey in order to give a real assessment of the state of a roadway. This process involves developing a numeric rating scale that gives a relative indication of road conditions. The developed rating factors in different type of distresses such as raveling, rutting, bleeding and cracking, and generally the more the number tends toward 10, the better the condition of the asphalt road. Based on the identified distresses along a road, it can be deduced whether the structural or functional requirements of the road has been impaired, to allow for necessary rehabilitation actions (FHWA, 1997). If the defects on the road are such that only the degree of rideability and skid resistance is affected, necessary solutions to improve the functional capacity are explored. On the other hand, if the level of deterioration is such that it affects the structural performance of the road way, major rehabilitation or sometimes reconstruction is recommended.

Irrespective of the affected capacity divide, placing an overlay on existing pavement remains one of the most frequently explored rehabilitation techniques. These overlays could be made of either Hot Mix Asphalt or Portland Cement Concrete. In the case where the existing pavement is Concrete, the options remain HMA overlay on PCC pavements, or PCC overlay on PCC pavements. On other hand, if the existing pavement is asphalt, the candidate choice is between PCC overlay on HMA pavements, or HMA overlay on HMA pavements. Exploring the concrete overlay type further reveals that there are two options; the bonded and the unbonded. As the name implies, a bonded concrete overlay requires a strong bond between the existing pavement and the constructed overlay, and thus perform best where the condition of the existing pavement can be tagged fair at the very worst. An unbonded concrete overlay on the other hand require no significant connection with the existing roadway. This rehabilitation solution is best for pavements that are badly deteriorated and offers a durable and time-saving alternative to reconstruction.

1.1 White Topping

White topping also known as PCC overlay on asphalt pavement is usually done to increase the structural capacity of a roadway [7]. It is a good rehabilitation solution for distresses in bituminous pavement such as rutting and shoving [9]. White topping is classified based on their thickness into three different types, namely:

- Conventional White topping (WT) with thickness greater or equal to 8in
- Thin White topping (TWT) with thickness range of 4-8in
- Ultrathin White topping (UTWT) with less than 4in thick of slab.

In terms of bond characteristic of the new layer and existing pavement, White topping, like other types of concrete overlays can either be bonded or unbonded. The choice of the type is hinged predominantly on the condition of the existing asphalt pavement and the extent of restoration required, if any.

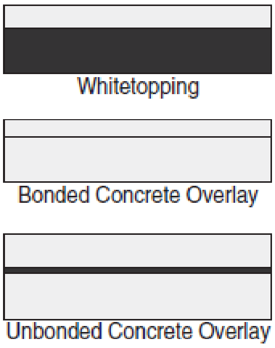

Fig -1: Concrete overlay types based on bond [3]

1.2 Objectives

The main objective of this paper is to discuss white topping, and synthesize different design and construction procedures, as well as recommend best practices adopted by CDOT and NJDOT for its use as a rehabilitation treatment.

2. LITERATURE REVIEW

White topping, otherwise known as a new Portland cement concrete overlay on HMA offers a suitable alternative to HMA overlays for asphalt pavement rehabilitation. This treatment technique has been in use for many years. The first one was built in 1944 on an airfield at the U.S. Air Force Base in Offutt, Nebraska [10]. According to [3], it can be classified based on thickness and the established bond type with the underlying HMA layer into:

- Conventional White topping (WT): This usually has a thickness of not less than 8in. The high thickness offers enough stiffness and strength for it to be designed and constructed without the need for interlayer bonding with underlying asphalt pavement. This type of white topping is mostly employed for preventive maintenance or minor rehabilitation, and is suitable for pavement in fair to good condition (Harrington, Fick et al. 2014).

- Thin White topping (TWT): TWT is typically designed and constructed for thickness range of 4-8in. The design requirement of ensuring a bond between the new PCC and underlying HMA layer must be adequately met. This thus mean that most TWT are designed as bonded concrete overlays, and would be most governed by the conditions of use of the overlay type. Most TWT and UTWT given their bond requirements are mostly used on poorly maintained and highly distressed roads as minor or major rehabilitation treatment (Harrington, Fick et al. 2014).

- Ultra-Thin White topping (UTW): Just like the TWT, the UTW requires a sufficient amount of bond with the underlying asphalt pavement in order to perform optimally. UTW however differs significantly in its thickness, which has to be maintained between 2 and 4in. It is important to note that for UTW especially, the bond helps to compensate for the relatively thin layer of overlay by increasing the strength through composite action. The bond also accounts for the reduced stress in the concrete layer by transferring some of the load to the underlying HMA layer.

Fig -2: Behavior of bonded and unbonded white topping under flexural action (Rasmussen and Rozycki, 2004)

2.1 White Topping Design

Based on the pavement condition evaluation, the existing HMA layer may bear many localized failures and significant base failures. A life-cycle cost analysis is then needed to be considered, which may reveal that bonded white topping is not the best. An unbonded white topping that is less sensitive to the underlying pavement condition may be more cost effective. Condition evaluation permits the pavement engineer to determine the quantity and location of pre-overlay repair required. It should be noted that random cracks in the underlying pavement do not necessarily lead to reduction in service life. Many miles of unbonded concrete overlays have been built that have performed very well with little regard or consideration to repairing the cracking in the underlying platform [8]. Major design considerations include existing asphalt pavement layer, pre-overlay repair, traffic, concrete materials, climate, white topping thickness, joints, transitions and other design feature [3].

2.2.1 Existing HMA Layer

According to the report by Darter, Hall et al. (1995), a uniform and stable support system, offered by the existing HMA layer holds the key to the success of white topping as a rehabilitation technique. For TWT and UTW, where the overlay and the asphalt pavement are designed to act as a single monolithic structure (Bonded Concrete Overlay), failure of the HMA pavement might similarly lead to a failure of the overlay [5]. Conventional White topping should be considered if the support layers have exhibited poor structural support, by contributing to the deformation and/or cracking of the original HMA pavement [4]. In the design of TWT or UTW overlay, due regard must be given to the condition of the existing HMA pavement. In some cases, this consideration includes the use of a reduced stiffness value for the HMA [5].

Rational adjustment factors for a decrease in the HMA stiffness owing to damage have been used in other pavement design approaches, and they could be used in white topping overlay design as well [3]. The stiffness of the existing pavement structure (including the HMA layer and support layers) is known to have a significant effect on the performance of the white topping overlay. As a result, Falling Weight Deflectometer test should be carried out. With proper characterization of the pavement support system, the reliability of the overlay design will be improved [5].

2.2.2 Portland Cement Concrete Materials

Conventional concrete mixes are easily employed for white topping, with fibers sometimes added to TWT and UTW. If the urgency of the rehabilitation is priority, mixtures with special rapid strength gaining properties without increasing shrinkage should be adopted [8]. To reduce surface spalling, and cracking, many white topping especially UTW use fiber to reinforce the concrete, since the relatively thin slab is susceptible to easy wear and cracking [3]. In the United States, most constructed UTW used fibers in the concrete. Examples of these fibers are steel fibers, synthetic monofilament and synthetic fibers, most commonly used at a rate of 1.8kg/m^3 [3].

2.2.3 Joint Design

The recommended joint pattern for bonded overlays of asphalt is small square panels, typically in the range of 3–8 ft (0.9–2.4 m), to reduce differential movement between the concrete overlay and asphalt and to reduce curling and warping stresses. For unbonded overlays, doweled joints are used typically like conventional rigid pavement design [8]. These joints may be used for pavements thickness in the region of 7in and beyond. For conventional white topping, the maximum spacing in feet is 1.5 x slab thickness in inches [8].

2.2.4 Traffic Characterization

Pavement truck loads are required to be accurately determined. Additional detailed information is also necessary for exact prediction of traffic, such as axle-load spectra, seasonal distribution of traffic, growth, and day-night duration [14].

2.2.5 Climatic Factors

Just like rigid pavement, climatic conditions during both construction and service life affect overlay behavior. Material should be compatible with weather conditions and joints should be provided depending on prevailing local seasonal changes in pavement temperatures [14].

2.2.6 Thickness

Reliability plays a very important role in choosing the thickness of white topping. This means that based on HMA condition evaluation, and other necessary considerations (like traffic), and having decided the type of white topping to use (i.e., whether WT, TWT, UTW), different desired level of achievement confidence would mean different white topping thickness. After white topping thickness is selected, it is checked for overhead clearance, and 13 curb and gutter. Reduction of the existing AC thickness is also a factor at this stage [14].

2.2.7 Transitions and other design features

During the design process, the transition area between the white topping and the adjacent Asphalt Concrete layer should be given proper consideration. A thickened slab is recommended for these types of transitions [14].

2.3 White Topping Construction

Typical white topping construction steps include pre-overlay repairs, milling, surface cleaning, concrete placement, curing and joint sawing [8].

2.3.1 Pre-Overlay Repair

It is important to carry out restoration on the existing HMA where necessary, before putting up the overlay, to provide necessary uniformity to the pavement structure for support. Although, white topping offers a superior treatment in term of curtailing reflective cracking as compared to using an asphalt overlay, some types of HMA distress may lead to different types of failures in the overlay. For example, a localized subgrade failure beneath the HMA that leads to alligator cracking may ultimately lead to faulting, roughness, or a shattered slab in the white topping, if left uncorrected [3].

There are two common pre-overlay repair methods: milling, which is most common, and filling/patching. Besides creating a surface to provide a good bond between the existing HMA pavement and the PCC overlay, milling is able to remove any permanent deformation and smooth out any surface distortions. However, since milling reduces the thickness of the existing HMA layer, special attention needs to paid to the minimum thickness recommendation for the existing HMA [12]. This stance is also further reinforced by Harrington, Fick et al. (2014) which suggests that milling should only be carried out to remove off the bad asphalt from the HMA layer. This is because an excess of it leads to loss of structural support offered by the pavement system. Asphalt deemed to be in good shape after condition survey will help contribute to monolithic action with TWT/UTW, and should thus be maintained to help carry traffic loads [8]. This thus mean that milling all asphalt layer with the aim of achieving correct bonding is a bad practice.

Typically, Harrington, Fick et al. (2014) defined the primary goals of milling as a pre-overlay repair technique for bonded TWT/UTW as:

- to remove significant surface distortions that contain soft asphaltic material, which would result in an inadequate bonding surface;
- to reduce high spots to help ensure minimum overlay depth and reduce the quantity of concrete needed to fill low spots; and
- to match curb or adjacent structure elevations. When this is the case, a thorough evaluation of the thickness and condition of the existing asphalt pavement must be performed to assure that the remaining asphalt to be overlaid is sound and thick enough to provide structural support for carrying loads.

Table 1 showing different types of existing pavement distress and suitable pre-overlay repair techniques for fix.

Table -1: Possible pre-overlay repairs on existing HWA [8]

Existing Pavement Distress	Spots Repairs to consider
Rutting ≥ 2 in. (50 mm)	Mill
Rutting < 2 in. (50 mm)	None or mill
Shoving, slippage	Mill
Crack width ≥ maximum coarse aggregate size used in the concrete overlay mixture	Fill with flowable fill.
Crack width < maximum coarse aggregate size used in the concrete overlay mixture	None
Low- to medium-severity pothole	Remove loose material and fill integrally with the concrete overlay.
High-severity pothole and/or areas needing full-depth repair	To prevent a single overlay panel from bonding to both asphalt and concrete, make full-depth repairs across a full lane width with concrete and adjust the transverse joint spacing in the concrete overlay to match the location of the underlying patch. The full lane width prevents trying to match a longitudinal joint for a partial lane patch.

2.4 Current Design Procedures

2.4.1 Colorado Department of Transportation

Tarr, Sheehan et al. (1998) proposed this method of white topping design to the Colorado Department of Transportation. Based on the field and theoretical analyses conducted, it is established that there exists a partial bonding, and temperature differential between the TWT/UTW and underlying HMA layer. Thus, the load-induced tensile stress and strain calculated for the two (2) layers must be reduced by approximately 25%. From the resulting stress and strain values, the allowable number of repetitions is determined using the performance model (Tarr, Sheehan et al. 1998).

The traffic input used in this design procedure is Load spectra.

Major consideration:

- Design equations for PCC stress and HMA strain are proposed for single and tandem axle loads only. The single axle load considered was 20kips while the 40kips load was considered for tandem axle. Stresses for the other single or tandem axle loads are computed as ratio of the 20-kip single axle load or 40- kip tandem axle load. A procedure using the 18-kip equivalent single axle loads (ESALs) is also proposed. Two highway categories (primary and secondary) in Colorado were anticipated as typical recipients of white topping treatment and thus the conversions factors for them were proposed as shown in the following equations.

  Primary highway: $F_{ESAL} = 0.985 + 10.057 * (t_{pcc})^{-3.456}$

  Secondary highway: $F_{ESAL} = (1.286 - 2.138 / t_{pcc})^{-1}$

where F_{ESAL} is the conversion factor from ESALs calculated assuming an 8-in concrete pavement and a terminal serviceability of 2.5 and t_{pcc} is the thickness of the white topping.

For material characterization, PCC modulus of elasticity, PCC flexural strength, coefficient of thermal expansion, HMA modulus of elasticity, and modulus of subgrade reaction are considered respectively.

- Concrete beams were tested at 28 days to determine their flexural strength. In the sensitivity analysis of the CDOT design method, 500, 650 and 800 psi were used for the flexural strength.
- Coefficient of thermal expansion input is not required in the CDOT design method, because the design stress is adjusted for the temperature gradient empirically, as mentioned earlier.
- The HMA resilient modulus was tested using cores from each of the three CDOT test sites and the results were 0.35 million, 0.8 million and 0.8 million psi. During the development of the CDOT structural model, 0.05 million, 0.5 million and 1 million psi were assumed for the HMA modulus of elasticity. In the design example, 0.6 million psi was used assuming 50 percent of remaining fatigue life and low-severity cracking for the existing HMA. There is no guidance to determine the HMA resilient modulus for design.
- In the development of the CDOT structural model, 75, 200 and 400 psi/in were employed for the modulus of subgrade reaction. This is mostly likely based on the field measurements, namely 150 psi, 225 psi and 340 psi for the three test sites. The design procedure provides no guidance on how to establish the modulus of subgrade reaction for design.

The geometry input considered a PCC overlay thickness of 4-7in thickness, HMA layers of 3-7.5in thickness, and joint spacings within 4-12ft depending on where the dowel bars were applied at the joint.

The effect of temperature gradients on the stress was also factored in. Temperature gradients were recorded for the test sections, which ranged from -1 to 5 °F/in

Two-dimensional FE software ILSL2 was employed to determine the tensile stresses at the bottom of each layer under 20-kip single axle loads and 40-kip tandem axle loads. Several finite element runs were carried out to establish empirical correlations, in order to predict the maximum stress and strain. The effect of temperature gradients on the predicted maximum stress was taken into account, and the stress-strain findings were considered to be evidence of partial interface bonding.

2.4.2 New Jersey Department of Transportation

The New Jersey Department of Transportation (NJDOT) design method (Gucunski 1998) works on a case to case basis for both bonded and unbonded pavement structure. The final design thickness is then linearly interpolated between the two thicknesses based on the degree of bonding assumed by the engineer.

The traffic loading is converted to equivalent 18-kip single axle loads (ESALs) by using conversion factors. The material characterization based on PCC modulus of elasticity, PCC flexural strength, PCC coefficient of thermal expansion, HMA modulus of elasticity, and Modulus of subgrade reaction respectively is as follows:

- PCC modulus of elasticity was assumed to be 3.4 million psi in the parametric study of the NJDOT structural model and 5 million psi in the design example.
- Flexural strength was determined based on laboratory testing
- PCC coefficient of thermal expansion was assumed to be 3.8 x 10-6
- HMA modulus of elasticity was between 0.88 to 1.66 million psi. In-situ tests, such as the falling weight deflectometer (FWD) testing were suggested for establishing this input
- The modulus of subgrade reaction was assumed from 145 to 580 psi/in in the parameteric study. Plate loading test was also suggested to obtain this input.

The geometry input considered a PCC overlay thickness projected within the range of 2.9 to 4.6 in. HMA cores for the tests ranged from 5.2 – 7.4 in, while the stress prediction equation does not employ joint spacing as an input.

The temperature difference of the overlay is needed to calculate the thermal stress. Based on the design example, a temperature differential of 3°F/in was used, which was multiplied by the trial 14 thickness of the PCC overlay as the temperature difference input for the design equation.

The PCC overlay, the existing HMA layer and the subbase layer were all simulated as linear, isotropic materials and the subgrade were represented by a set of Winkler springs, as shown in Figure 4. In order to investigate the effect of bonding on the induced stresses, the interface layer was simulated as an anisotropic layer that was 0.5 in thick (thin compared to the 3- to 5-in PCC overlay and the 4- to 8-in HMA layer used in the modelling).

The maximum stress in the PCC layer was identified at the bottom of the layer. Both fully bonded and unbonded conditions were considered in the stress prediction equations. Interpolation was needed to get the corresponding stress for the actual partial bonding at the discretion of the engineer.

3. CONCLUSIONS

The foregoing makes a case for white topping as a great rehabilitation technique for hot-mix asphalt pavement. It presents a much-needed background on the technique, based on the increasing demands on transportation agencies [16]. It also reviews important past works using white topping, while looking at two case studies of Colorado and New Jersey DOTs. The recommended best practices on design and construction procedures from these agencies are brought to the fore, for possible contrasting and adoption by other agencies. The paper also talks about the different design and construction requirements of white topping.

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