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Experimental investigation of interface treatment technique on interface shear bond fatigue behavior of Ultra-Thin Whitetopping

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HIGHLIGHTS

- Presents the HMA-UTW composite results under static and dynamic loading conditions.
- Groove interface and piercing interface treatment technique on HMA-UTW were studied.
- Fatigue life of piercing interface treatment with varying contact area was evaluated.
- Fatigue life model was proposed for HMA-UTW composites.

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ABSTRACT

The bonded concrete overlays on existing asphalt pavements are classified into three subcategories namely whitetopping, thin-whitetopping and Ultra-Thin Whitetopping (UTW). The design service life of UTW overlays depends on several factors such as interface bond strength, slab thickness, slab size, material strength and underlying material condition. The quality of the interface bond depends on both surface preparation and the UTW placement procedure. The interface bond between two layers helps in the monolithic action of the pavement section by shifting the neutral axis from the middle of the UTW slab to the bottom of UTW slab. The composite action had a direct impact on the long-term performance of the UTW overlays. To assure good bonding, milling method is usually applied at the interfaces during UTW overlay construction. The interface bond strength due to milling technique can be measured with the help of several devices arranged by different laboratories. This paper investigates the interface shear bond strength and shear fatigue behavior of UTW pavement for different interface treatment techniques. For this experimental purpose, a laboratory direct shear testing method and procedure was used. Two interface treatment technique like groove and piercing method have been analyzed. Interface treatment with piercing technique had shown highest shear bond strength and k-modulus values. Incorporating groove interface technique with an inclination of 0–45 degrees and piercing interface treatment has been proposed. The interface shear bond fatigue behavior of piercing treatment technique with different debonding conditions are discussed. As expected the increase in debonding leads to decrease in interface shear stress and fatigue performance.

1. Introduction

1.1. General

The term "Whitetopping" refers to the construction of a Portland cement concrete (PCC) layer over an existing asphalt pavement [1–6]. It is a rehabilitation technique used to address distresses in asphalt pavement, such as rutting and shoving [7,16]. Based on the thickness, whitetopping is further classified into three sub categories such as conventional whitetopping (>200 mm), thin whitetopping (100–200 mm) and Ultrathin Whitetopping (UTW) (50–100 mm) [8,9]. UTW is the new emerging technique for resurfacing of asphalt pavements due to its low cost of construction. Because of its shorter joint spacing and bonding to the underlaying asphalt layer, it reduces the bending stresses compared to conventional and thin whitetopping. The UTW has been developed for low volume roads, intersections, city streets, parking areas, where rutting, wash boarding and shoving of the asphalt are a problem [3].

The interface bond between existing asphalt layer and concrete is the major criteria for the performance of the UTW overlay. Specific construction techniques are usually considered to ensure adequate bond is achieved. However, in UTW bonding can be

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achieved by milling the existing asphalt pavement to produce a clean and roughened surface for freshly laid concrete overlay [4]. The bonding between two layers causes monolithic action and share the load by shifting the neutral axis from the middle of the UTW slab to the bottom of UTW slab. This will bring the bending stresses into a range the UTW can withstand, but shear stresses will remain maximum at the neutral axis [10]. Further, shear stresses will increase with the increase in the repeated application of traffic load which creates an accumulation of strain at the interface resulting in failure of the monolithic or composite action. The same mechanism (internal stresses induced by gravity loads) will govern the interface debonding of the UTW from the HMA layer led to cracking and eventually surface distress problems and finally affect the long-term service life [11,12]. Therefore, UTW had better interface bond strength than the normal tensile stress and horizontal shear stress caused by traffic and environmental load.

The quality and strength of the bond between the layers depend on both the surface preparation i.e., specific construction technique [13], the texture of HMA surface and the UTW placement procedure. Hence workmanship will play a major role in achieving good quality and strength of the bond between the substrate and the overlay. But field observations, emphasize the need to ensure a sound bond between two layers, especially on road sections where vehicles are more likely to apply horizontal forces and turning action such as parking lots, steep ramps and intersections [14]. The good bonding also reduces the common occurrence of abrasion and erosion of individual pieces of aggregate under traffic. Hence the bond strength criteria are considered to be important in the design of UTW overlays.

From the literature review (see Table 1) it can be seen that various agencies were adopted different surface preparation methods to achieve the degree of bonding. Later the bond strength was evaluated in the laboratory using Iowa shear test [15] and their own measuring methods. Some of the measuring method and criteria for evaluating the interface bond strength are shown in Table 1.

In India the degree of bonding is achieved as per IRC SP: 76 2008, between UTW overlay and the existing HMA layer to obtain 100% bonding at the interface. In reality, the 100% bonding is not always achieved, and the interface characteristics are unknown functions of the interface treatment, curing time and construction practices. From the literature (see Table 1) no work has been carried out on the interface shear bond characteristics of UTW overlays subjected to static and repeated loading conditions for different interface treatment. Therefore, it is essential to evaluate the interface bond condition of the UTW overlays for different interface treatment and its impact on long-term performance. In this study, a new interface treatment technique is developed and laboratory direct shear test apparatus and method were used to evaluate the behavior of UTW overlays for different interface treatment techniques when subjected to static and dynamic loading conditions.

2. Interface shear bond strength test

The direct shear test apparatus has been fabricated (Fig. 1), which is a modified version of equipment developed by authors [21,43]. The modified direct shear test apparatus was used to evaluate the interface bond strength of UTW overlay on HMA layer under laboratory condition.

2.1. Test apparatus

The direct shear testing device consists of three segments, upper and lower cylindrical segments and a semicircular shearing head segment. The lower segment is fixed to the bottom plate and the upper segment is placed on the specimen. The upper and lower cylindrical segments act as a stationary sample holder, whereas the shearing head segment moves down during shear force application. A 5 mm gap was maintained between the stationary sample holder and shearing head segments, to allow the direct shear load at the interface. The effect of bending moment induced by the eccentricity of the vertical load was eliminated by using horizontal locking plate at the top is shown in Fig. 1. The Linear Variable Differential Transducers (LVDT's) are placed over the shearing head segment for measuring specimen deformation during shearing.

2.2. Interface treatment

Milling is the most commonly used and recommended interface treatment technique for placing UTW overlay because it is the most effective method for rutting and shoving problems in the existing asphalt pavement and gives higher shear bond strength [3,4]. The milling method was carried out in the field in the direction of traffic. From the findings [4] even though milling is adopted in the field the required bond strength and performance is not full filling the design life criteria.

In order to overcome these issues, a new interface treatment techniques such as (i) groove interface with an inclined angle of 45 degrees and (ii) piercing interface was developed under laboratory conditions to evaluate the interface shear bond strength of UTW overlay. Further, in the field, it is difficult to identify the percentage of bonding between two layers for the existing interface treatment method. Hence, the present study investigates the interface shear bond fatigue performance of interface treatment technique with varying contact area at the interface.

2.3. Material

The standard Ordinary Portland Cement (OPC-43 grade) meets the requirements of IS 8112-2001 [35] used in the present study. Ground Granulated Blast Furnace Slag (GGBS) of IS 12089-1987 [36], and Silica Fume (SF) of IS 15388-2003 [37] were used as a partial replacement of OPC. In order to improve the workability of the concrete mixture, a commercial naphthalene superplasticizer agent (SP430) of IS 9103-1999 [38] was added. Recron 3s polyester fibers were used in the present study and its physical properties are shown in Table 2.

The locally available natural river sand was used as fine aggregate and crushed granite as coarse aggregate with 20 mm Nominal Maximum Aggregate Size (NMAS) were used. The water absorption and saturated surface dry specific gravity of coarse aggregate and fine aggregate values are 1.0%, 2.68 and 1.1%, 2.58 respectively. Fiber Reinforced Concrete (FRC) mix design for UTW samples are shown in Table 3 and its 7 and 28 days average compressive strength are 44 MPa and 52 MPa and average flexural strength 7.5 MPa and 8.5 MPa respectively. The paving bitumen 60/70 grade was used and its physical properties are measured in the laboratory according to IS 73-2013 [39] and are shown in Table 4. The percentage of combined flakiness and elongation index was less than 30%, which is the requirement for dense asphalt mixture. For dense asphalt mixture, the aggregates of different sizes were used in suitable proportions by trial and error method to obtain the average proportions of grading as specified by MoRTH (Ministry of Road Transport & Highways) [40]. The aggregate gradations for HMA and UTW mixtures are shown in Table 5.

Table 1
Summary of laboratory test methods for evaluating interface bond strength.

Test method	Overlay type	Interface treatment	Bond strength (MPa)	References
Shear test	Asphalt-Asphalt overlay	Tack coat	0.8–3.6	[17–24]
Torque	Asphalt-Asphalt overlay	Tack coat	0.9–2.9	[25]
Wedge splitting	Asphalt-Asphalt overlay	Tack coat	NA	[26]
Shear test	Asphalt-Concrete overlay	NA	0.7–1.13	[27–29]
Pullout test and Wedge splitting	Asphalt-Concrete overlay	Adhesive agents	0.8–1.7	[30]
Splitting tensile	Concrete-Concrete overlay	Rough surface	2.83	[31]
Collar test and Pull off test	Concrete–Concrete overlay	Rough	0.816–0.158	[32]
Shear test	Concrete-Asphalt Overlay	Smooth and rough surface	0.05–0.4	[33]
Shear test	UTW	NA	1.13–2.11	[34]
Pull off test	UTW	Smooth and rough surface	1.4	[11]
Shear test	UTW	Polymer modified cement, groove and shear-key	0.41–1.28	[45]

Note: NA- not available.