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A State-of- Art Review on the Interfacial Bond Strength of Bituminous Overlay in Asphalt Pavements

Ammu B Crusho[1], Sai Niveditha M G[2]
[1](Dept. of Civil Engineering, Jyothi Engineering College, Cheruthuruthy, Thrissur, India)
[2](Dept. of Civil Engineering, TKM College of Engineering, Kollam, India)
*Corresponding author: Ammu B Crusho

ABSTRACT: *This paper intends to provide a brief review of the various techniques to evaluate the interface bond strength of Bituminous Overlays. Bitumen Overlays are typically placed over tack coated surfaces. However premature delamination failure and crescent shaped cracks appear on the pavement surface, reduce service life of overlays. These failures occur due to excessive shear stresses which are developed at the interface. MORTH (Ministry of Road Transportation and Highways) has given specifications about the amount of tack coat (bitumen emulsion) that has to be applied over the pavement surface above which it is overlaid. However, bond strength mobilized at the interface depends largely on the characteristics of residual binders (i.e., Bitumen Emulsion), binder content, existing texture of pavement surface, gradation of overlaid material, thickness of bituminous overlay. Other than the techniques to evaluate interfacial bond strength, the various parameters that affect the interfacial bond strength have also been discussed in this paper.*

***Keywords** – Delamination, Interface Bond Strength, Residual Binders.*

I. INTRODUCTION

Early detection of pavement failures pays paramount importance in reducing the detriment of roads and other transportation mechanisms to a massive amount. The investigation of some of the recent trends in pavement failure detection that use the current state of the art methodologies and strategies and which emerged from greenhorn procedures have been studied in detail in this research analysis work. This paper also presents a compiled study of various methods for studying interlayer bond strength and its variations on the grounds of different parameters. Studies also show that the use of ultrasonic techniques can also be used with an appreciable level of efficiency for delamination detection. It is evident that there is room for improvement in each of the methods surveyed in this paper. The behaviour of asphalt pavements under diverse conditions is also one of the points which have been brought to light by this paper. The next section describes the various methods under the field of study that have been developed so far.

II. RESEARCH ON LITERATURE

Jyothi Prakash Giri et al. [1] conducted a study for evaluation of the bond strength between the pavement layers. They fabricated a simple testing device namely Interlayer bond strength tester (Installed in a Marshall Test apparatus) and used for the evaluation of bond strength offered by the tack coat at the interface between the bituminous layers. Aggregate gradation was selected based on Nominal Maximum Size Aggregates (NMSA) as per MORTH as aggregates and Portland Slag Cement passing 0.075mm IS sieve was used as fillers in DBM, BC BM and SDBC layers. Experiments were conducted varying the test temperature, type of tack coat material and application rate of respective tack coat. Test temperature was selected based on Indian conditions. In their experimental study, they used RS and MS emulsion, VG 10 and VG 30 as tack coat material. It was observed that MS Emulsion was good in using as a tack coat material in both DBM-BC and BM-SDBC layer combinations for achieving maximum Interlayer Bond Strength whereas VG 30 Bitumen could not be used. It was seen that the testing temperature had a significant influence on the bond strength and no proper specification for the curing time of tack coat was seen. Experimental data was limited, filed core samples evaluations had to be conducted, interlayer bond strength had also to be evaluated varying the thickness of Bituminous layer, diameter of the specimen and varying the rate of application of load was the future scope of the study observed.

Weiguang Zhang [2] conducted a study to quantify the effects of tack coat type, tack coat application rate, and surface type (i.e., hot-mix asphalt versus Portland cement concrete) including milled versus unmilled surfaces on the interface shear strength based on full-scale test application. Variation of interface shear strength between field and laboratory prepared samples were studied. They varied, five types of tack coat materials, which were applied at three application rates on four types of surfaces. Samples were cored from the constructed test lanes, and the interface shear strength was measured using the Louisiana Interface Shear Strength Tester. They studied on various factors that affect the tack coat application on interlayer shear strength on Asphalt pavements. A direct relationship was obtained in this study, between the roughness of the existing surface and the developed shear strength at the interface. It was found in theoretical study that a small amount of water seemed to negatively affect interface shear strength with PG 64-22 used as a tack coat material. Thus, the effect of surface wetness on interface shear strength was less evident for emulsion-based tack coat materials. A decreasing trend was observed in the laboratory, and an increasing trend in the measured interface shear strength was observed in the field.

Weimin Song et al. [3] investigated the factors affecting the shear strength between open graded friction coarse aggregate and the underlying layer through laboratory testing. Tack coat application rate, temperature and the mixture of underlying layer were the factors considered in the study. Mixture selected for the study was dense graded surface mixture and one type of stone mix Asphalt. Four tack coat application rates and test temperatures were varied in the experiment. At low temperatures asphalt was so stiff and at high temperatures the shear strength did not show a change. It was found that due to increase in temperature the shear failure mode between OGFC and underlying layer changed from plastic to brittle. The underlying layer should have adequate roughness in order to provide proper bonding between the OGFC aggregates. Thus, it was concluded that the friction between the OGFC and underlying layer is an indicator of surface texture depth of underlying layer.

Nithin Sudarsanan et al. [4] analysed the interlayer bond strength between the asphalt pavement layers that is reinforced with a geosynthetic product impregnated with asphalt as a tack coat material. A study was conducted on shear strength behaviour of the reinforced asphaltic concrete layer with respect to geosynthetic products at varying temperatures. A test pavement constructed as part of the research was subjected to durability and performance test. Great variations in bond strengths at different scenarios of lower strain rate together with higher temperatures and higher strain rates were caused due to the self-weight of the material. Research also proposed a method verified and backed by test data of CGT to determine bond strength on the basis of strain rate and temperature based on the strength at 10°C. Nithin Sudarsanan et al. inferred that lower viscosity of asphalt in conjunction with an increment in the temperature resulted in an 80% reduction in bond strength. An inverse proportional relationship between geosynthetic modulus and bond strength was one of the findings of the research. An effort to compute the consequence of geosynthetic on the interface strength was also made as part of research.

Antonio D'Andrea et al. [5] with the use of two testing machines SISTM and SHSTM, made an extensive study of the correlations between various configurations, failure techniques, and states of stress forced by testing machines. Research uses response curves obtained from the two devices and a comparison was setup based on the outcomes. Similar specimens were used for testing and the outcomes were compared. Another main objective of the study was to verify the statistical reliability of both machines. No performance variations were recorded on interlayer shear strength, hence resulting in a peak shear stress data distribution. Reviewing using specimens of identical features with normal load equal in the average value pointed out analogous outcomes on the grounds of shear strength. Results from studies showed that normal load and shear response were interrelated. A direct proportion between shear strength and normal load was identified on a condition where the SHSTM interlayer tangential modulus had a steady value for compression load which is higher than the average value achieved on the SISTM test device. The research also shed light on the correlation between peak shear strength, interlayer tangential modulus and the specimens' features.

Xinxin We, et al. [6] conducted a study to investigate the influence factors on shear strength, including types of tack coat, application rate, upper layer type, test temperature, as well as interface contamination. A test device that was capable of applying normal stress was employed to evaluate the shear properties between layers. Self-developed polymer modified emulsified asphalt performed best among all the tack coats. The interface contamination between layers significantly decreased the shear strength. Test temperature was proven to be the most significant factors that affect the shear strength. Results provided a meaningful information on the selection and installation of tack coat between pavement layers. It was concluded that high temperature, high water content of emulsified asphalt and the existing of oil, dust all have a negative effect on bonding effect.

Cristina Tozzo et. al. [7] conducted an interlayer fatigue performance evaluated by the Sapienza shear testing machine. It was performed by placing double layer specimens in several inclinations, in order to reproduce a variety of expected ratios between the normal and the shear stress. The machine managed loads with any kind of waveform and was particularly able to simulate the stress trends expected in field in points located just outside the wheel path. Load was applied by the machine in a triangular waveform computed by a linear elastic multilayer program at the depth of the first pavement interface. A fatigue law is estimated considering the number of repetitions that caused the interface failure and a linear regression in the log-log graph was used for fitting the experimental results for the analysed conditions of temperature and interface type.

Kammal Hossain et al. [8] conducted a Finite Element-based software program (ABAQUS) to evaluate the interlayer damages between the existing pavement and overlay. Various interface conditions were modelled for evaluating the performance of the overlay. The results were obtained from the analysis such that it could help in selecting appropriate maintenance strategies for developing a sustainable overlay construction specification. It was said that many past studies reported that the life of overlays primarily depends on the interface condition between the existing pavement and overlay. Overlay could also fail mainly due to lack of proper maintenance for existing pavement before constructing the overlay. Various interfaces between AC overlay and existing PCC pavement were modelled using the finite element-based program, for evaluation of performance of pavement and following conclusions were observed. Due to an increase in interface bond strength between the AC overlay and existing PCC pavement, the strains at the bottom of the AC overlay were reduced, which corresponds to the high fatigue life of the pavement. Combination of tining and a tack coat performance were observed well when the application rate of tack coat is less; but at the optimum application of the tack coat (provides a smooth interface) can provide better bonding than a tined interface. An overlay without any interface bonding will lead to the premature cracking of pavement was their final conclusion.

Stefan A. Romanoschi et al. [9] proposed a new constitutive model for the asphalt concrete layer interface. Direct shear tests at four levels of normal load and three temperatures were performed on two types of asphalt concrete layer interface: with and without a tack coat. Shear stress-displacement curves determined in these tests were used to derive the constitutive model, as the tangential and normal stresses at the interface are decoupled. In the proposed model, the shear stress and displacement are proportional until the shear stress equals the shear strength and the interface fails. After failure, a friction model was used to represent the interface condition. Three parameters were considered to completely describe the interface behaviour: the interface reaction modulus K, which is the slope of the shear stress-displacement curve; the shear strength S_{max}; and the friction coefficient after failure μ. For the interface with a tack coat, K and S_{max} are not affected by the normal stress level, but they are affected for the interface without a tack coat. A testing configuration for determining the shear fatigue behaviour of the interface was also described. The fatigue test was used for a comparative evaluation of the durability of different types of interfaces. The fatigue test could be used for a comparative evaluation of the durability of different types of interfaces. Further research may indicate ways to optimize the bond between the overlay and the existing surface in terms of preparation of the surface and the type and quantity of bonding material to be used.

Jian-Shiuh Chen et al. [10] conducted a study to analyse the effect of surface characteristics on bonding properties of bituminous tack coat. The study was conducted using two emulsions, three surfacing types, three test temperatures, four normal stresses, and six residual emulsion rates. The interlayer reaction tangential modulus, shear strength, and residual shear strength at the interlayer were evaluated by the direct shear test. The use of a tack coat to increase the peak shear strength was more effective for dense-graded mixtures as compared with gap- and open-graded mixtures. An increase in Mean Texture depth (MTD) enhanced the interlock after the peak shear stress, and it increased the interlayer residual stress. He also said that a change in the Film thickness (FT) might cause the reduction in the boding properties. The shear resistance and the reaction modulus decreased with increasing temperature, and they increased with increasing normal stress. Residual application rate varied with the tack coat type and the interface characteristics. Increasing the residual application rate did not significantly improve the shear strength at the interlayer. Viscosity of the tack coat played a role in influencing the bond strength at the interface. It was said that the tack coat needed to be cured before the new pavement layer was laid since the peak shear stress increased with curing time. The bond properties at the interlayer were shown to depend on the surface characteristics.

Hoegh et. al. [11] presented an evaluation of using an ultrasonic technique to detect delamination in asphalt pavements. They focused on a detailed assessment of the use of tomography devices in finding out the type and amount of delamination. They developed dry point contact transducers which were able to penetrate great depths using low frequency elastic waves to study delamination effects. From the results, it was proved that ultrasonic tomography is an efficient method to determine delamination in the interface between new and old AC. They could also prove that Synthetic Aperture Focusing Technique B- and D-scan methods proved handy to check the presence of delamination between new and old asphalt interfaces. In order to spot delamination in asphalt lifts, a different focusing method was used. This study also proposed that SAFT-FW tests to be elaborated so that it could work on larger trends. To study the effect of temperature and diverse binder types on ultrasonic tomography, additional testing efforts are required. Another discovery from this study pointed that the efficiency of ultrasonic tomography could be catapulted to a higher level if an initial screening in combination with higher speed non-destructive methods were used, which in turn drilled down the sections to be tested to the ones which were only suspected for the presence of delamination.

Michael Heitzman et. al. [12] proposed non-destructive testing methods to identify and quantify delamination in HMA pavements and aimed at presenting the findings of the SHRP 2 Renewal Project R06D - phases 1 and 2. The study also proposed a 3d-Radar Report with efficient Real-Time Processing and Post processing configurations focusing on the modelling of a Delamination Detection Algorithm. The setup was a 3d-Radar system, which was constituted by the core components - GeoScope, Antenna Array and Vehicle Mount. The algorithm worked by isolating a sub volume which was highly probable to delamination and conducted an energy-based study of frequency intervals on the sub volume. This resulted in the upper hand of getting the samples have much information about the depth range in study. The algorithm then worked its way on 'bins' which were basically spectrum divisions of frequency intervals. Each bin's value was extracted and sorted. Finally, the user selects a value relative to one bin. The final output is generated based on a threshold value and the minimum size for an anomaly of interest. Results of Phase-2 subcontract research tried to study delamination using spectral analysis of surface waves and impact echo (SASW and IE) tests. 3 test sites were studied - NCAT Test Track, Florida Pavement and Kansas Pavement. The study also developed a Bridge Deck Scanner Hardware, which could detect near-surface delaminations. Other tweaks helped to increase the test area coverage of a single pass and hence greatly reduced the time requirements. Phase-1 research proved that IE test method results were more accurate and reliable in pointing out de-bonded asphalt conditions, while SASW test threw light on the detection of shallow debonding. Various upgrades to the IE/SASW were proposed as part of research.

SHRP2 Solutions [13] proposed methods to pinpoint delaminations in asphalt pavements using non-destructive testing systems. The focused on identifying delamination between asphalt pavement layers in a single pass having full lane coverage. Their research made way to 2 new techniques for delamination detection. The Ground Penetrating radar system was equipped with a lane-width multi-antenna array making use of frequency sweeps that could be made to operate at speeds up to 40 mph. This system had the merit of reducing the number of passes needed to complete the entire lane. Automated test frequency modules also expedited the ability to acquire data. Next in the list was the IE-SASW system, which had the huge dominance of collecting the data much faster when compared to the slow manual point testing. Pavement conditions could be analysed almost quickly since the system employed the use of real-time displays. This is turn tossed out the time and safety issues with manual point testing. Enhanced GPR technology is highly advantageous as it reduces the lane passes to fetch the necessary amount of data. Reduction of time requirement is another advantage as a result of the above. The study also explained that frequency sweeps assisted the radar signal to penetrate the pavement for complete surface examination in one pass. This study also proves that the updated technology helps in narrowing down manual analysis to identify locations where in the GPR signal differed.

A. Moropoulou et al. [14] proposed an infrared thermography technique to detect delamination in airport pavements. The study concentrated on the International Airport of Athens and by using the above technique, tried to detect and quantify delamination. The basic principle of this study was that given a structure, thermography could identify the temperature differences on the surface, and delamination and other disorders result in temperature differences. This study extensively used infrared thermography with consideration for other environmental factors in determining delamination disorders. The method in the study also highlighted the advantages of non-destructive techniques over destructive techniques for delamination detection. The research also confirmed, from the results that roads and runways could be scanned fast using non-destructive techniques, thereby having a great reduction in time consumption, machinery and manpower requirement. The technique discussed in this study is risk free as it records only the radiation emitted from the surface under observation. Being an area investigation technique, the drawbacks of other non-destructive techniques did not affect the proposed method. Moreover, the methodology was time independent - meaning that it could be used anytime taking into account the environmental conditions. The main curb of this method is its inability to accurately find out the dimensions of delamination.

Yusuf Mehta et al. [15] in this work, studied the behaviour of top pavement layers as a result of poor bonding between HMA surface and the bonds below. This approach also outlined the usual approach to detect interlayer bonding problems and discussed the limitations of this methodology. The primary objective of this work was to find out the interlayer bonding failures and propose prevention measures. Other objectives of the research include confirming the root cause of slippage damage to be failures at pavement layer interface, to propose guidelines for reducing slippage cracking, and to determine the surplus thickness required in upper pavement layers. A falling weight deflectometer aided in determining stiffness ratios and a high value corresponded to a good stiff and nicely bonded pavement structures. This work also put forward steps for developing design and treatment recommendations. Experimental results confirmed no-distress sections had higher stiffness ratio than high-distress sections and also discovered a relation between stiffness ratio and probability of slippage. The collected FWD data also helped in finding interlayer bonding failures. The study also proposed that efficient forensic use of FWD data could be handy in recovering rehabilitation costs. Early signs of slippage development were also discussed in this study. Future scope of this research included proposing methods to achieve the required stiffness and bond in rough pavement overlays. Interlayer debonding causes also needed to be studied in detail. Materials that could be used for getting favourable bonds between HMA pavement layers are also to be identified in the future using Tack-coat application.

Dante Mejia Munoz et al. [16] discussed on the importance of identifying and fixing delamination failures in Hot Mix Asphalt Pavements so as to ensure prolonged life of the pavement. As a result, they studied 3 methods - Impact Echo, Ultrasonic Surface Waves and Impulse response. Experimental evaluations of these 3 methods were completed using a Finite Element software (LS-DYNA, a tool which could simulate result behaviour from delamination detection, and a detailed analysis of the results were made. The evaluation phase included the analysis of methods like IE-FEM, FE, USW-FEM, IR-FEM. IE-FEM results were close to theoretical values. USW-FEM results proved reliable to be used for detecting delamination using USW. It was confirmed that delamination could be manifested on this method by a severe drop in velocity with total recovery of velocity. It was also understood that USW could not identify faults in the bottom layer. Another finding was that the place of the device had significant impacts on the outputs. Results of the IR-FEM in combination with that of IR method could be used for detecting delamination. IR method worked on the principle that a high probability exists for delamination to be present if we have a large amplitude and large FFT. The study also noted that small and deep delaminations appeared obscure to the IR method. Future scopes of this work promise an improved FE model, which could deliver much more realistic results and could be an efficient tool in delamination detection.

Panda et. al. [17] explored the influence of setting time of tack coat on the bond strength on a bituminous layer combination. The tack coat type, application rate and the test temperature were the factors considered. Two types of bituminous emulsions (CRS 1 and CMS 2) and two types of bituminous binders (VG 10 and VG 30) have been selected as tack coat for a typical bituminous layer combination. Conclusions from their study was out of the four tack coat materials, CMS 2 offers the maximum interlayer bond strength with minimum quantity requirements in the bituminous layer combination considered. Highest interlayer bond strength is when no tack coat is used, however the upper layer is to be laid and compacted immediately after the lower layer.

Louay N. Mohammad et. al. [18] conducted a study to quantify the effects of tack coat type, tack coat application rate, and surface type (i.e., hot-mix asphalt versus Portland cement concrete) including milled versus unmilled surfaces on the interface shear strength based on full-scale test application. Variation of interface shear strength between field- and laboratory prepared samples was investigated. They used five types of tack coat materials were applied at three application rates on four types of surfaces. Samples were cored from the constructed test lanes, and the interface shear strength was measured using the Louisiana Interface Shear Strength Tester. They observed a direct relation between the roughness of the existing surface and the developed shear strength at the interface. Water seemed to negatively affect interface shear strength in small amount with PG 64-22 (used as a tack coat material). However, the effect of surface wetness on interface shear strength was less evident for emulsion-based tack coat materials. Laboratory-prepared samples grossly overestimated the interface shear strength when compared with field extracted cores. While a decreasing trend was observed in the laboratory, an increasing trend in the measured interface shear strength was observed in the field.

Mohd Imran Kumar et.al. [19] worked on contriving testing apparatuses to benchmark the bond strength given by the application of tack coats in between bituminous layers. They studied the change in bond strength by varying the amount of tack coat applied. They also focused on studying on selecting the best tack coat material and its ideal amount which was to be applied. They divided their work into two phases – experiment phase and the bond strength evaluation phase. In the first phase, they experimented on different materials such as aggregates, bitumen, and emulsions and at the second, they worked on building various testing devices for bond strength evaluation. They used Aggregates (cylindrical samples composed of Dense Bituminous Macadam (DBM) and Bituminous Concrete (BC)), Coarse Aggregates (stone chips), and fine aggregates (stone crusher dusts), fillers (Portland slag cement (Grade 43) and binders (VG 30 bitumen) were used for experimentations. Emulsions CMS-2 and CRS-1 were picked as tack coats for study. A modified Layer-Parallel Direct Shear (LPDS) was used to record the shear force and the corresponding displacement. The influence of compaction, surface texture, moisture, heat and water on the interface shear bond of pavements with the usage of 20 types of tack coats was closely monitored. It was noted that smooth specimen surfaces had a higher degree of shear strength. They could also find out that moisture and no tack coat presence adversely affected the shear strength. Shear adhesion was boosted by 10% for a top-layer compaction by 240 gyrations by using a certain tack coat.

III. CONCLUSION

Pavement nowadays are getting deteriorated before their design life period, so there arises a need in investigating the causes of these failures. Overlaying is one of the main techniques that is provided as a measure to regenerate the roads when they are distressed. But even after overlaying, the pavement starts deteriorating mainly due to slippage failure i.e., delamination. It is caused due to lack of interlayer bond strength. Various techniques have been developed to evaluate the interlayer bond strength so that a proper bonding can be provided in between the overlaid and existing pavement. The various factors that affects the inter layer bond strength have been discussed along with the various techniques for measuring the interlayer bond strength. Thus, upon reviewing all these factors it could be made sure that an overlaid pavement could be in a distress free condition till its design life time.

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