INFLUENCE OF THE TACK COAT MATERIAL ON INTERLAYER BONDING PROPERTIES IN ASPHALT LAYERS SYSTEM

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ABSTRACT

Lack of proper interlayer bonding causes a significant decrease of an asphalt pavement durability. In this case bituminous layers work separately what induces the negative changes of values and stress distributions in a pavement structure. Therefore, it is important to know, which material provides optimum interlayer bonding conditions.

In this paper Authors undertake the problem of different tack coat materials to show their influence on the strength and durability of an interlayer bonding in asphalt layers system. Modified bituminous emulsion and latex-bituminous emulsion, as well as geosynthetic interlayer in asphalt layers system have been applied at the contact surface of the layers.

The paper presents the results of comparative monotonic and fatigue tests carried out for different types of tack coat materials applied in the tests.

1 INTRODUCTION

Lack of a proper interlayer bonding results in a significant decrease of asphalt pavement durability. Bituminous layers work separately what negatively changes stress and strain distribution in a pavement structure (Canestrari et al. 2005), (Górszczyk, 2010).

A number of factors determine the condition of an interlayer bonding. The first group of them is related to execution work quality. During works on the road a site traffic can contaminate the surface of lower layer. The second group is connected with weather conditions. An execution of interlayer bonding within period of rainy or cold weather may result in shorter durability. The third essential factor refers to the properties of a tack coat material applied for asphalt layers bonding and types of binding material.

Different types of hot mix asphalt require different amounts of a tack coat. In case of asphalt mixtures with quite a high bitumen amount, the amount of tack coat should be chosen carefully, so as not to weaken an interlayer bonding by an excess of a tack coat material amount.

Bituminous emulsion and hot road bitumen are the materials mostly used as a tack coat. Recently, new types of material, e.g. latex-bituminous emulsions have been introduced. Also, geosynthetic interlayers, that additionally influence the condition of an interlayer bonding, can be placed between asphalt layers. They are applied as bituminous layers strengthening, or stress relieving membranes over cracks in lower, rigid layers, to protect the upper bituminous layers against the reflective cracking. Geogrids and geocomposits are commonly used for reinforcement, whereas e.g. unwoven are used for stress relieving purposes.

The number of factors influencing an interlayer bonding properties and its importance for the proper work of an asphalt road structure make this element of pavement structure a subject for detailed tests and analyses. It is important to realize how a given tack coat material affects the quality of a bonding between layers of asphalt pavement structure.

This paper presents results of tests and analyses carried out to determine influence of a tack coat material on strength and fatigue life of bonding. Laboratory tests were performed for a bonding between the wearing course and the binding layer. At the same time, the finite element method was used for numerical calculations of the shear test simulation for asphalt mixture specimens in the Leutner's device.

2 RESEARCH METHODS

2.1 Monotonic test method

Monotonic tests were carried out with the Leutner's method which was developed in Germany (FSGV, 1999) and implemented to the Polish road laboratories (Sybilski et. al 2010).

The parameter which describes the adhesion quality between asphalt layers is the maximum shear load in an interlayer bonding. Shear strength of an interlayer bonding is expressed as a ratio of the maximum shear load to the initial shear area of specimen. The relationship between the shear force and displacement recorded during the test is presented in Fig. 1.

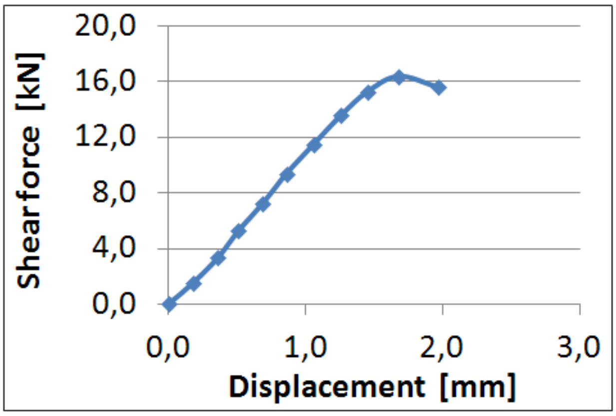

Figure 1: Shear force – displacement curve during monotonic test for a specimen of diameter 100 mm.

In monotonic tests a typical testing stand was used for testing an interlayer bonding by the Leutner's method. See Fig. 2. A vertical load was generated by the Marshall press with a fixed movement speed of 50 mm/min. This press allows to read and record the vertical displacement and shear load during the test.

Monotonic and fatigue tests were carried out at temperature of +20°C.

Figure 2: Monotonic shear load testing stand

2.2 Fatigue test at the shear cyclic load

In interlayer bonding fatigue tests, the Leutner's device (Fig. 2) and the Nottingham Asphalt Tester (Fig. 3) were used.

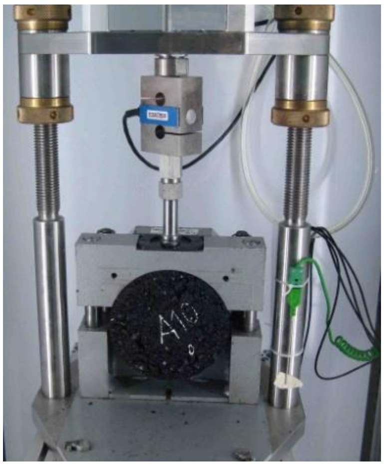

Figure 3: Fatigue testing at the shear cyclic load stand

The concept of the method was developed at the Institute of Road and Railway Engineering of the Cracow University of Technology. The test results presented below are based on the first research done with using this method. The method has been still being developed and improved (Malicki, 2012).

Cyclic tests were carried out for controlled stress of the asymmetry coefficient of the cycle R=0. The load frequency of 0.833 Hz, the load duration of 240 ms and the rest period of 960 ms were applied.

The shear fatigue test method is based on Van Dijk's dissipated energy concept (Van Dijk, 1975). It was first used for an indirect tension fatigue test on asphalt mixture specimens by Rowe (Rowe, 1993) and then in Germany by Leutner's team (Leutner, 2006). This method assumes three phases of material damage: the initial stabilization period, the initialization and propagation of micro cracking, and the initialization and propagation of macro cracking to the break of the material. It is based on the assumption that the total dissipated energy for a specimen break is the function of the number of loading cycles to failure, different for each asphalt mixture type. At sinusoidal loading the dissipated energy in a cycle in testing material can be represented by the equation:

$$W = \pi \cdot \sigma \cdot \varepsilon \cdot sin\varphi \quad (1)$$

where W – dissipated energy per cycle, per unit volume [J/m^3], σ, ε – stress and strain amplitude [MPa], [-], φ – phase angle [rad].

The energy dissipated at the beginning of the test and the energy dissipated in a given loading cycle can be presented as *ER* – a ratio of these two types of energy. For tests run by the controlled stress method the Energy Ratio can be represented by the product of a asphalt mixture stiffness modulus at a given loading cycle and a number of loading cycles – *N*. On the basis of the graph's curve of the Energy Ratio during the test, it is possible to determine the moment of micro and macro cracking formation (Hopman et al. 1989).

To calculate the Energy Ratio a shear stiffness modulus ΔK [MPa/mm] was used. The modulus being defined as (Diakhate et al. 2008):

$$\Delta K(N) = \frac{\Delta f}{A \cdot u(N)} \quad (2)$$

where: Δf – shear load range [kN], u – maximal displacement per the cycle [mm], A – initial specimen shear area [mm^2].

The final form of the Energy Ratio *ER(N)* used for fatigue shear tests was taken from the following formula:

$$ER(N) = \Delta K(N) \cdot N \quad (3)$$

In the next stage the maximum of *ER(N)* function was assigned. It was identified with the formation of macro cracks in the tested interlayer bonding and accepted as a damage criterion. Fig. 4 shows an exemplary plot of the Energy Ratio changes during the interlayer bonding fatigue test.

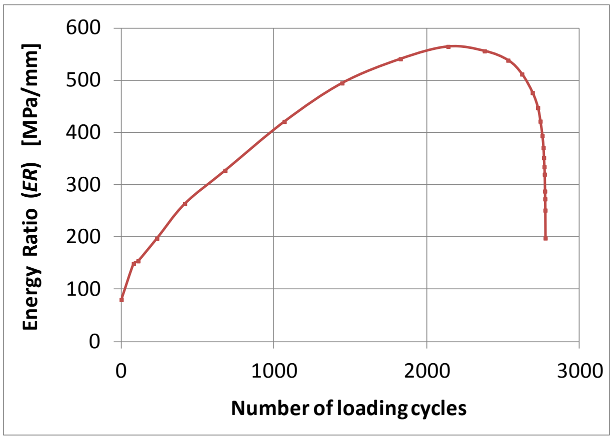

Figure 4: Energy Ratio plot during interlayer bonding fatigue test for a specimen of diameter 150 mm.

Interlayer bonding fatigue test results for different tack coat materials were presented by Wöhler fatigue curves in the system – $\Delta\tau$ (the range of shear stress) – N (the number of the load cycles leading to macro cracks).

2.3 Finite element method to determine shear stresses

To determine the distribution of shear stresses in a specimen and to evaluate the range of shear stress required to describe the work of a bonding in tested specimen (Wöhler curves) numerical analyses with using the finite element method (FEM) were performed.

A geometric model was constructed for the Leutner's device and for asphalt mixture specimens with diameter of 101.5 mm and 150.0 mm. The material properties: both the steel of Leutner's device and asphalt mixture, were assumed to be linear elastic. The steel was described by elasticity modulus E = 210 GPa and the Poisson's ratio ν = 0.2. Asphalt mixture specimens were described by appropriately selected stiffness moduli and by the Poisoon's ratio ν = 0.35 (linear elastic material model). The contact conditions between the device and a asphalt mixture specimen were described by Coulomb friction model with the friction coefficient μ = 0.5. The Leutner's device was put under a static load of different values depending on the character of tests and within the range between 1 kN – 35 kN.

The geometric model of the device and the specimen of 150 mm diameter as well as the mesh of the FE model in software ANSYS are presented in Fig. 5.

a) b)

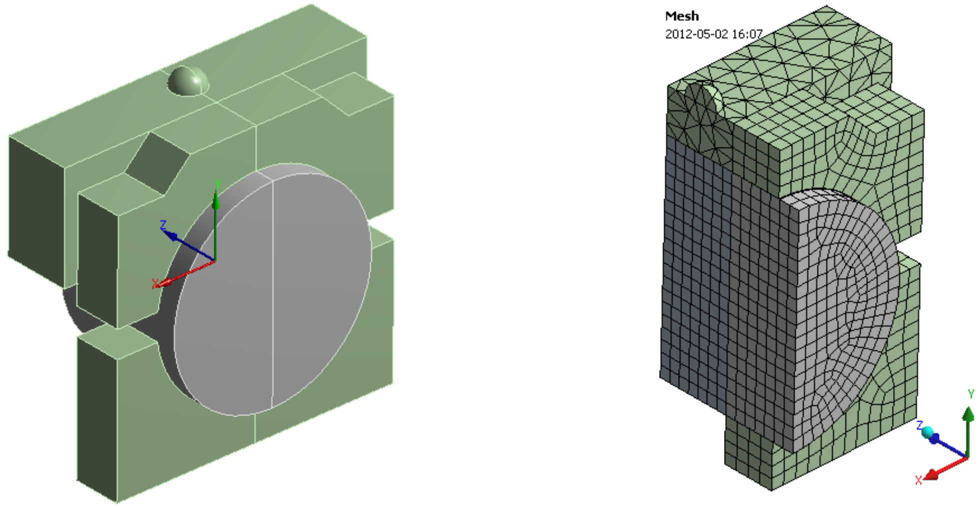

Figure 5: a) Geometric model for specimen of diameter 150 mm together with global system of coordinates XYZ, b) The mesh of the FE model with symmetry plane (elements from library of ANSYS: 20−node solid element SOLID186, 8−node contact/interface elements TARGE170 and CONTA174).

Selected results of numerical analyses in form of shear stress distributions in a tested specimen are presented in Fig. 6.

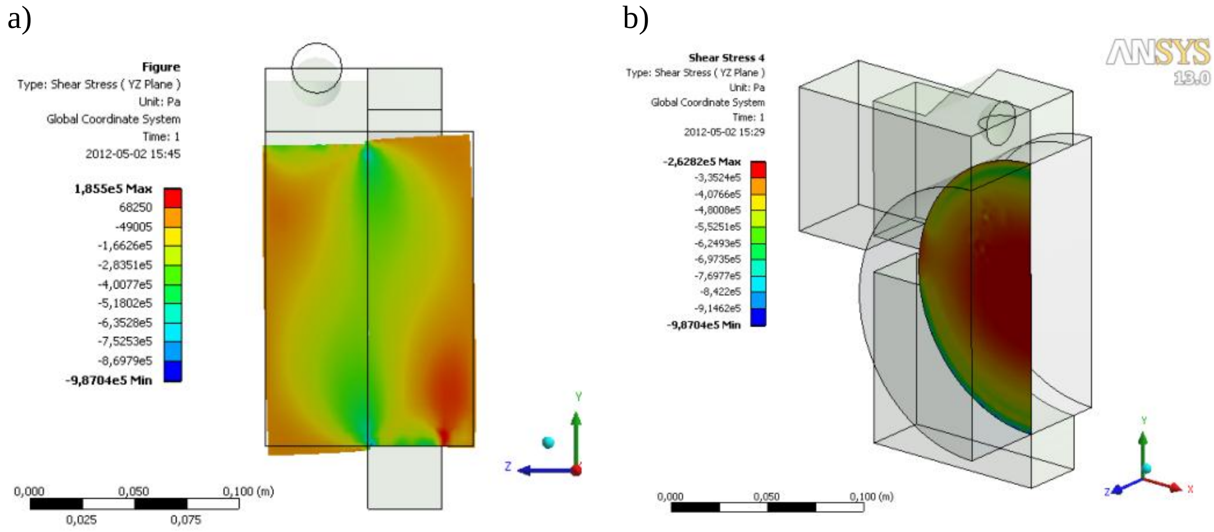

Figure 6: a)YZ shear stress distribution – side view (the symmetry plane), b) in cutting plane – front view, for shear load of 7 kN

The problem was solved as nonlinear due to the change of stiffness in the whole system caused by the change of contact between the device and a specimen. A partial sliding and a separation between the surfaces of the device and asphalt mixture specimens were observed. Solutions were computed by the iterative Newton-Raphson procedure.

The results of numerical simulations were similar to the ones described in literature (De Bond, 1999). An accumulation of stress at a specimen's edges and their continuous distribution in the inner area of the cutting plane were found. (Fig. 6)

Fixing conditions of the specimen during the test greatly affected stress distribution inside the specimen's material, especially since the specimens were of relatively small diameters. Thus, the damage process probably started on the specimen's edge at the point of the local stress accumulation.

3 APPLIED MATERIALS AND SAMPLES FABRICATION

In both monotonic and fatigue tests the same variants of interlayer bonding was tested. The interlayer bonding was tested between wearing and binder courses. This bonding was chosen because the maximum shear stress zone is usually located in this area of a pavement structure. (Judycki, Jaskuła, 2002)

Stone mastic asphalt was used for the wearing course (SMA 11) and asphalt concrete for the binding course (AC 20). Both mixtures were made of asphalt mixture with polymer modified bitumen. The bitumen content in SMA was equal to 6.0% and in asphalt concrete equal to 4.5%.

The laboratory tests were focused on the influence of different tack coat materials on interlayer bonding strength when a wearing course had quite a high bitumen amount. During the processes of asphalt mixture laying and compaction bitumen from the SMA wearing course can increase the amount of the tack coat material.

Layered cylindrical specimens were produced from mixtures with the static compaction method. The compaction force was optimized in order to obtain air void content according to the Polish technical requirements (Sybilski, at al. 2010). Fig. 7 presents a series of produced specimens (left) and an example specimen where the edge of contact surface is marked (right).

a) b)

Figure 7: Series of specimens prepared for tests a) and specimen where the edge of contact surface is marked – side view b)

Two types of tack coat materials were analysed with regard to bonding strength and durability. Treatments with bituminous and latex-bituminous emulsions were applied. The results were compared to the results of interlayer bonding tests done without a tack coat and additionally to results of tests with a geosynthetic interlayer. Table 1 presents variants of interlayer bonding conditions.

Table 1. Variants of interlayer bonding conditions

Description of interlayer bonding	Series indicator
Modified bituminous emulsion tack coat	F
Latex-bituminous emulsion tack coat	J
No tack coat	G
Geosynthetic glued by modified bituminous emulsion	H

In series F there was used a polymer modified bituminous emulsion of type C60 BP 3 ZM designed for a tack coat. The amount of the bituminous emulsion in the tack coat was equal to 0.20 kg/m^2, taken as the average of the Polish requirements (Sybilski, D et al 2010).

In series J there was used a latex-bituminous emulsion of the trade name Flexigum HP, which is typically applied as a hydroisolation (Flexigum HP, 2009). Applied amount of latex-bituminous tack coat was equal to 0.30 kg/m^2, what was a little lower than amount recommended in the manufacturer’s instructions. Series G was prepared by laying the SMA layer on the AC layer without a tack coat. In H series a glass-carbon geogrid Carbophalt G manufactured by S&P Reinforcement and designed as the asphalt layer reinforcement (Aprobata Techniczna, 2008) was applied as a geosynthetic interlayer. For gluing the geosynthetic the same emulsion as in the F series was used. The amount of the emulsion of 0.18 kg/m^2 was contained in the range recommended by the manufacturer. The emulsion and the geosynthetic were spread manually.

The specimens with the geosynthetic interlayer and the latex-bituminous emulsion were of diameter 150.0 mm, whereas the others were of diameter 101.5 mm.

4 RESULTS

4.1 Monotonic test result analysis

For the series F, G, and H monotonic tests were carried out on four specimens for each series. For the latex-bituminous emulsion (series J) the tests were carried out on six specimens.

The average shear strength for the bonding without a tack coat was equal to 2.38 MPa, for the bituminous emulsion 2.33 MPa, for latex-bituminous emulsion 1.84 MPa, and for the geosynthetic interlayer 1.41 MPa. The results are graphically presented in Fig. 8.

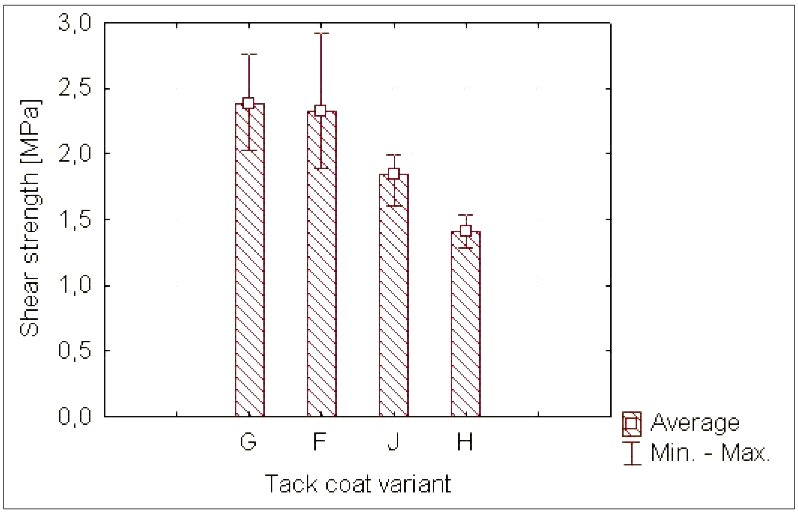

Figure 8: Average value and a min. – max. scatter for shear strength for variants of tack coat: without tack coat (G), bituminous emulsion (F), latex-bituminous emulsion (J), tack coat with geosynthetic (H).

For all types of tack coat materials used for tests, the interlayer bonding manifested the high shear strength, over 1.30 MPa, recommended in the Polish requirements for bonding between wearing course and a binding layer (Sybilski, at al 2010), however, the shear strength in the bonding surface with a tack coat was smaller than in the bonding without a tack coat.

The asphalt mixtures were produced with polymer modified bitumen, the bitumen content in SMA was equal to 6.0%, so SMA mixture contained a relatively large amount of bitumen. During the mixture laying and compaction processes some amount of bitumen from SMA layer in samples without the tack coat produces the bonding similar to a tack coat. Thus, spraying additional material in order to produce a tack coat in this area does not always increase shear strength of the bonding. The excess of a tack coat material can produce a sliding surface and consequently deteriorate the quality of an interlayer.

The lower shear stress for the latex-bituminous emulsion compared to the bituminous emulsion was probably caused by its volume. The applied amount of the latex-bituminous emulsion was equal to 0.30 kg/m^2, which was much greater than the amount of the bituminous emulsion modified with polymer (0.20 kg/m^2).

For tested asphalt mixtures samples i.e. SMA on AC, application of tack coat material reduced the shear strength.

4.2 Cyclic shear test result analysis

To widen the analysis of the influence of tack coat materials on interlayer bonding characteristic, the cyclic tests with the previously described method were carried out.

Fatigue tests for the interlayer bonding without a tack coat were carried out on 27 specimens, for the bituminous emulsion on 25 specimens, for the latex-bituminous emulsion on 15 specimens, and for the geosynthetic interlayer on 26 specimens.

The obtained results underwent the regression analysis and Wöhler fatigue curves presenting interlayer durability were developed. The coefficient of determination of the model without a tack coat was equal to 0.74. The coefficients of determination of other series were contained in the range 0.81−0.86. The models presented in logarithmic – logarithmic coordinates system are presented in Fig. 9.

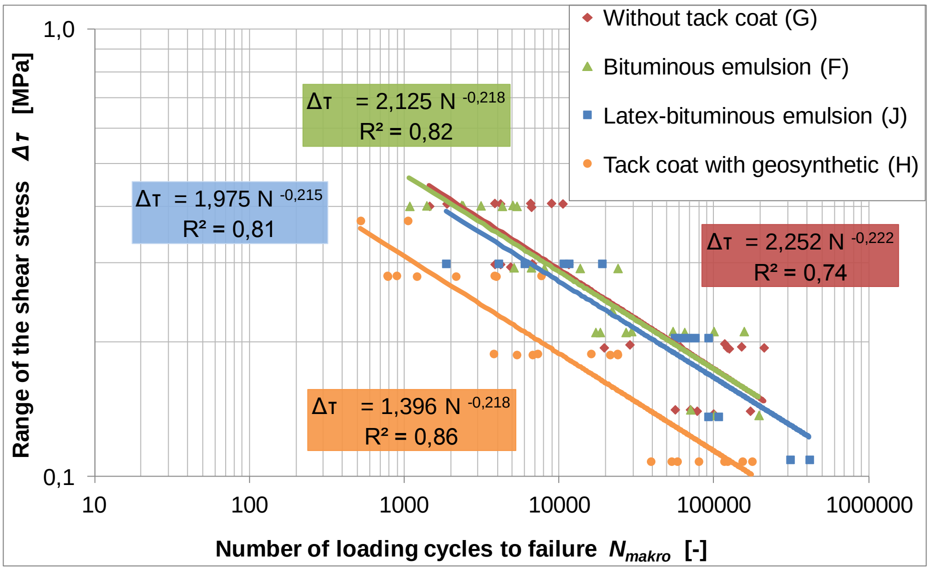

Figure 9: Wöhler fatigue curves for analysed interlayer bonding

The character of obtained results differ from results presented in literature, but for samples of AC (Diakhate et al. 2008). In case of asphalt mixtures, i.e. SMA on AC, using the tack coat material did not improve bonding durability under the given test conditions and within the analysis range.

Some relatively big dispersion of fatigue test results was observed. The results presented in the Fig. 9 are the first ones obtained with the application of the proposed method, which has been still being developed and improved.

5 CONCLUSIONS

Both the static Leutner's method and the shear fatigue method with FEM allow us to evaluate the influence of a tack coat material on interlayer bonding strength and durability. The applied shear fatigue method for interlayer bonding is still under development and needs further improvements.

For all tested types of tack coat materials, interlayer bonding manifested a high shear strength, above 1.30 MPa as recommended by the Polish requirements for the bonding between a wearing course and a binder layer (Sybilski, at al 2010).

In the tests performed for SMA on AC, laying an additional tack coat material did not improve the strength and durability of interlayer bonding.

The basic conclusion drawn from the analysis is the necessity of optimization of the type and amount of a tack coat application, especially when dealing with bituminous mixtures containing a high bitumen amount.

On the other hand, a tack coat, in the cases when it is increasing interlayer durability, is also supposed to reduce water penetration into a pavement structure. This aspect should be kept in mind while optimizing the durability of interlayer bonding.

Multi-aspect character of the presented problem indicates on necessity of undertaking the detailed tests and optimization for interlayer bonding, similarly as in case of asphalt mixtures used for pavement structures. It is very important to realize the influence of a tack coat material on interlayer bonding quality and durability.

Comparative tests of specimens prepared in laboratory and specimens cut from actual pavement structure should be performed on the more extended scale. Bonding obtained in the in-site are affected by some additional factors e.g. site traffic, weather conditions which can change the shear strength of an interlayer bonding in comparison to specimens produced in a laboratory.

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