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Section: Roads and Railways

Influence of compaction effectiveness on interlayer bonding of asphalt layers

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Abstract

The paper presents the results of research on the interlayer bonding of asphalt layers compacted in the laboratory and in the field. To measure the interlayer bonding at a temperature of 20 °C the Leutner test apparatus was used and load was applied at a rate of 50 mm/minute. Three types of interlayer interfaces were tested: no tack coat and tack coats made of two types of the pure bitumen emulsions. Four compaction techniques were used in laboratory conditions: rolling with and without vibrations, gyratory compaction and compaction with slab compactor, including both hot-to-cold and hot-to-hot. The fields specimens cored from pavements differed in terms of relative compaction. It was found out that interlayer bond strength between the layers of asphalt dependeds strongly on the applied compaction technique, as well as the compaction effort. In some cases efficient compaction produced a maximum shear force without tack coat. The type of emulsion used as the tack coat was also found to be highly relevant to the interlayer bonding.

Keywords: interlayer bonding; tack coat; Leutner shear test; asphalt layers; compaction of asphalt layers.

1. Introduction

The interlayer bonding between asphalt layers has a strong influence on the distribution of stresses and strains in the pavements subjected to traffic loads [1]. Lack of or insufficient bond between the asphalt layers increases pavement deflections resulting in greater tensile stresses and strains created at the bottom of the respective layers. Unfavourable load conditions when accompanied with bad condition of the pavement structure may result in premature distresses (e.g. deformations, bulging, side shifting or cracking) which can decrease the service life of the pavement. A measure commonly used to ensure the desired bonding between the asphalt layers is application of bituminous tack coat sprayed on the contact surface. For successful tack coat performance it is of critical importance to identify and understand the factors which are relevant to the tack coat design and application. Leutner shear test developed at the end of 1970 [2] is one of typical method used to evaluate tack coat performance. Among the different factors affecting the interlayer bond strength [3, 4] the primary factors influencing the interlayer bond strength are the type of tack coat and the degree of compaction of the layers of asphalt, in particular of the upper (overlying) layer. The influence of the tack coat type on the bond strength has been examined and reported in many scientific articles and technical reports [5–10].The effect of the proper degree of compaction has been reported in various publications [6], [8], [11]. The effect of good quality of compaction of asphalt layers on the bond performance was also examined on cores cut out from the existing pavements [12], [13].

The recent research confirmed the reported findings, i.e. a strong influence of the compaction technique and effort on the interlayer bonding of the asphalt layers. In some cases the maximum shear strength was attained by good compaction on its own, i.e. without any tack coat applied between the layers. It was also found that, the type of emulsion used for tack coat has a strong influence on the bond strength.

The article presents the results of three research projects which were carried out independently at the Department of Highway Engineering, Gdansk University of Technology. The tests were done in 2006 and 2013 at the Road Research Laboratory of the Gdansk University of Technology. Some tests were carried out on cores cut out from the new constructed pavements of selected main roads in Poland. Specimens were tested by the relevant road administration laboratories.

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2. Materials and methods

The interlayer bonding performance between the asphalt layers was examined on two-layer specimens produced in laboratory or cut out from the following pavements: trial section on a local road and several new constructed pavements on the main road network in Poland. The laboratory and field specimens cut out from the trial section were tested at the laboratory of the Gdansk University of Technology, while the other cores were tested by the relevant road administration laboratories.

2.1. Asphalt concrete

The specimens prepared in the laboratory were made of asphalt mixtures compacted in two layers. The lower layer was made of AC22P asphalt concrete obtained by mixing granite aggregate with 4% (by weight) of plain bitumen type 35/50. The upper layer was made of AC20W asphalt concrete obtained by mixing granite aggregate with 4,2% (by weight) of plain bitumen type 35/50. The mixtures were designed according to the requirements of PN-EN 13108-1 and NA. The two mixes were produced in the selected supplier's asphalt plant. The particle size distribution curves of the two mixes are presented in Fig. 1.

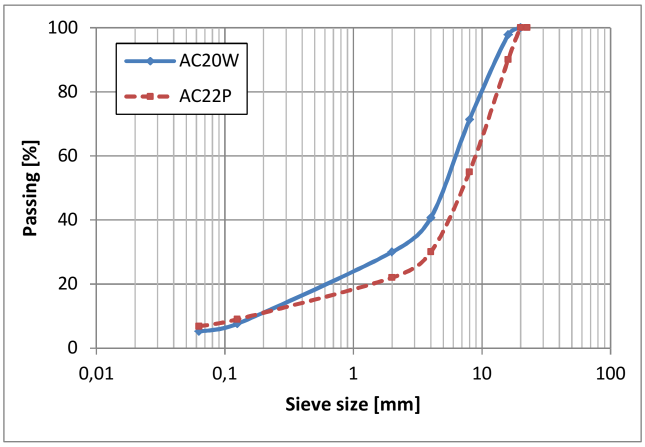


Fig.1. Particle size distribution curves of aggregate mixture used to produce the tested asphalt concretes

Trial section was constructed using different asphalt concrete mix design. Their recipes were presented in report [8]. For the purpose of this study only the bond strength between the wearing and binder course was examined.

In field specimens cut out from selected main roads in Poland, the wearing course was made either from asphalt concrete or stone mastic asphalt and binder and base courses were made from asphalt concrete. Bond strength was examined for wearing/binder course interface [13].

2.2. Tack coat

Tack coat was examined in four different configurations: no tack coat, no tack coat but hot-to-hot placing or hot-to-cold placing, tack coat made from two different types of bitumen emulsions. Type 1 of the bitumen emulsion was produced from 160/200 plain bitumen. It was the standard material used for asphalt paving works in Poland till 2006. Type 2of the bitumen emulsion was produced from 70/100 plain bitumen. It has been recommended as tack coat material since the introduction of PN-EN 13808 standard. Both laboratory and field specimens included the tack coat obtained by spraying the surface of lower asphalt layer with bitumen emulsion at a rate of 0.3–0.4 kg/m^3.

2.3 Mixing and compacting of specimens in laboratory conditions

Laboratory specimen were cut out as 150 mm cores from two-layer slabs compacted in laboratory with four compaction techniques:

- rolling with a small (465 kg) static roller (used for the upper layer of the slab only),
- rolling with a small vibrating roller,
- compacting using Cooper CRT-RC2S standard laboratory slab roller compactor according to PN-EN 12697-33 standard,
- gyratory compaction according to PN-EN 12697-31 standard.

The upper layers were in all cases placed and compacted at least 24 hours after compaction of the bottom layer. The tack coat was applied one hour before placing the upper layer of asphalt mixture.

Slabs compacted by rolling were the size of 900 mm × 1200 mm, comprising of 6 cm bottom layer and 4 cm upper layer. The bottom layer was compacted by rolling with vibrations and the upper layer was compacted by rolling with and without vibrations. The slabs compacted by laboratory slab compactor were the size of 305 mm × 305 mm and comprised of layers of the same thicknesses as in the case of roller compaction. Gyratory compaction was done on 150 mm cylindrical specimens made by placing asphalt in two lifts of 10 and 6 cm in thickness. The 150 mm cores were cut out from the compacted slabs after four days from compaction and the specimens compacted in gyratory compactor were de-moulded after one day. All the specimens were compacted to obtain the predetermined height and Marshall bulk specific gravity.

2.4 Preparation and compacting of field specimens

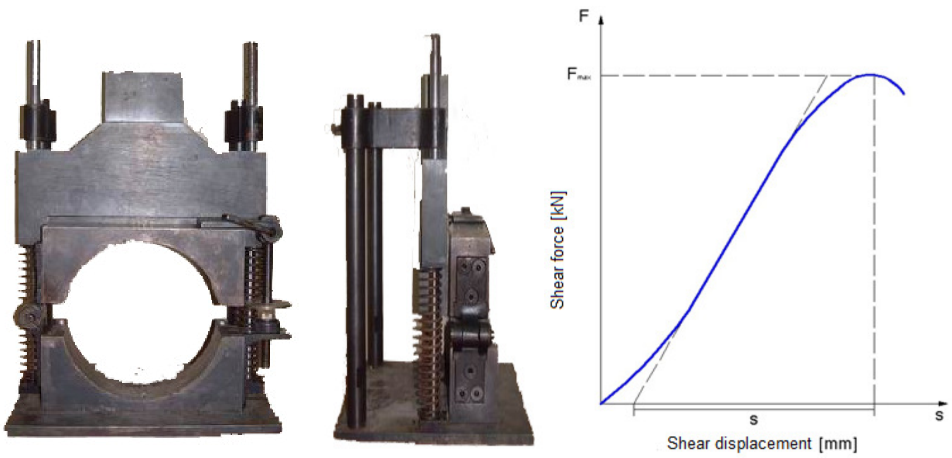
The trial area was located on a section of local road and consisted of three sections up to 20 m in length and 3 m wide (lane width). In the case of the constructed pavements, standard compaction technique was used i.e. by rolling with a road roller. The tack coat was applied the next day after placement and compaction of the bottom layer and one and a half hours before placing the upper layer. The 150 mm cores were cut out ten days after placement and compaction of asphalt layers.

Field specimens obtained from main Polish road network (at almost 50 locations) were cut out usually two days after placement and compaction of the examined layers.

2.5. Leutner shear test

The interlayer bonding was examined with the direct shear method developed by Leutner in 1979 and described in the manual [5]. In the Leutner test shear force is applied directly in the plane of interface between the two-layers of 150 mm cores using the test frame, which eliminates bending moments. The controlled parameters are the shear force and shear displacement. In this research shear force was applied at the core to obtain shear displacement rate of 50.8 mm/min, thus producing fracture in the predetermined shear plane. There were no gaps between the shearing rings (the width of gap was 0 mm) the same as in the original procedure. Before the test the specimens were conditioned in a climate chamber for twelve hours and then tested at a temperature of 20 °C.

The shear strength which in Poland is the parameter used to evaluate bonding between layers was determined on the basis of the maximum shear force measured during the test and the contact area at the interface between the asphalt layers.



a) b)

Fig. 2. Shear test set-up and results a) view of shear test apparatus, b) an example of graph (shear force vs. shear displacement)

3. Experimental research programme

The objective of the research was to investigate the effect of the compacting technique on interlayer bonding between the asphalt layers by testing the specimens prepared in laboratory. This information will be very important and useful in evaluation of the results obtained in the Leutner test. It will be also very helpful to find the causes of lack or insufficient bond between the layers. Another objective of the research was to investigate the effect of compaction quality in field conditions on the bond strength determined on field specimens. The type of tack coat was another factor relevant to the bond strength. It was evaluated simultaneously with the effect of compaction tested both on specimens prepared in laboratory and cut out from installed pavements.

The effect of the compaction technique, quality of compaction and the type of tack coat on the bond performance between the asphalt layers was evaluated by the Leutner test. The test was carried out at the temperature of +20°C on laboratory and field specimens, which differed in terms of tack coat application configuration.

The compacting techniques, tack coat configurations and quantity of two-layer specimens are presented in Table 1.

Table 1. Quantity of specimens for each preparation procedure

Compaction method	Quantity of two-layer specimens						
	Prepared in the Laboratory			Cores cut out from trial section			Cores cut out from Polish road network pavements
	No emulsion	Type 2 emulsion	No emulsion, hot-to-hot technique	No emulsion	Emulsion Type 1	Emulsion Type 2	With emulsion similar to Type 2
Vibrating roller	2	2	2	-	-	-	512
Static roller	2	2	2	3	3	3	-
Laboratory slab roller compactor	2	2	2	-	-	-	-
Gyratory compactor	2	2	2	-	-	-	-

4. Results and analysis

The results of bond strength tests done in 2013 for three tack coat configurations and four compaction techniques are presented in Fig. 3. All the values in the diagram were calculated as the mean value of two results obtained on the same type of specimens. As it can be seen, interlayer bonding of asphalt layers strongly depends on the type of tack coat and type of compaction technique used in the laboratory conditions.

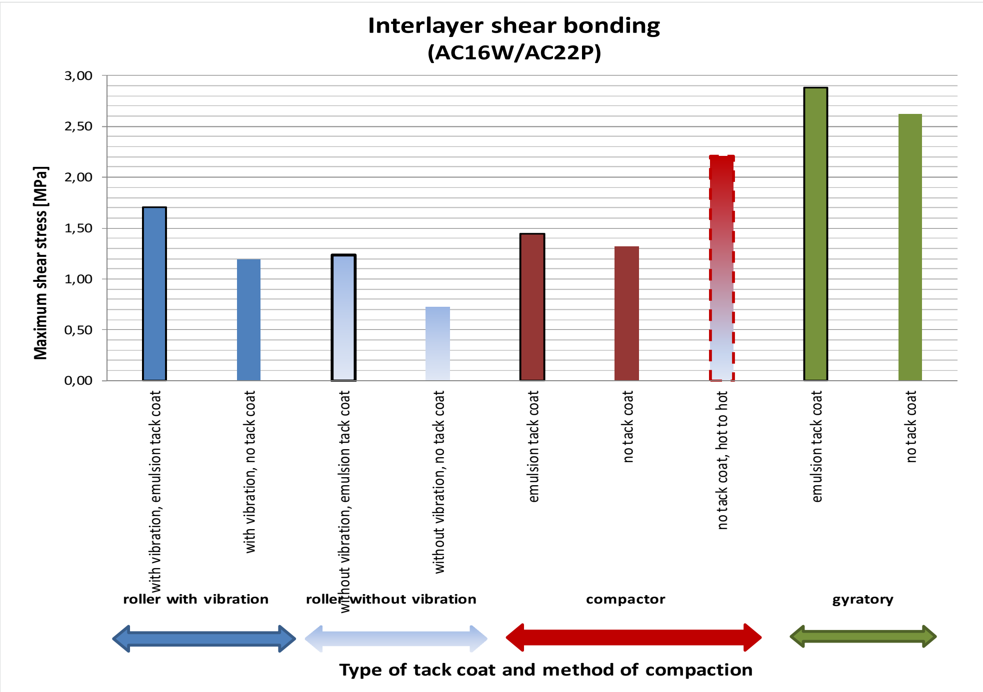


Fig. 3. Maximum interlayer shear stress for different tack coat configurations and different compaction techniques applied in laboratory conditions

It was found that in almost all cases, a special, dedicated tack coat emulsion made with harder bitumen (50/70 plain bitumen) gave a higher bond strength than the specimens where emulsion was not used. There was an exception for the specimens produced with the hot-to-hot technique. The high shear strength values measured in that case confirmed the efficiency of hot-to-hot technique for construction of asphalt pavements.

Note that the bond strength was similar for compaction with vibrating roller and laboratory roller compactor. Compaction with static roller produced slightly lower bond strength values. The lowest laboratory bond strength was noted on the specimens without tack coat and with the upper layer compacted by static rolling. Gyratory compaction produced the highest bond strength, whether or not tack coat was applied between the asphalt layers. These observations are very useful in comparing the laboratory bond strength results with differences as high as 100%.

Fig. 4 presents the maximum stress values measured in the shear strength test conducted in 2013 depending on the compaction technique used. As it can be seen, the method of compaction affects the maximum stress induced inside the layer during the shear test. These results follow the trend observed in the case of interlayer bond shear strength test, with the highest values obtained for gyratory compaction and similar values obtained in the case of laboratory roller compactor and vibratory roller.

As it can be figured out from Fig. 4 and Fig. 5 in the case of specimens including tack coat the maximum interlayer shear stress values are sometimes higher and often very similar to the maximum shear stress measured inside the asphalt layer (less stiffer binder course in this case).

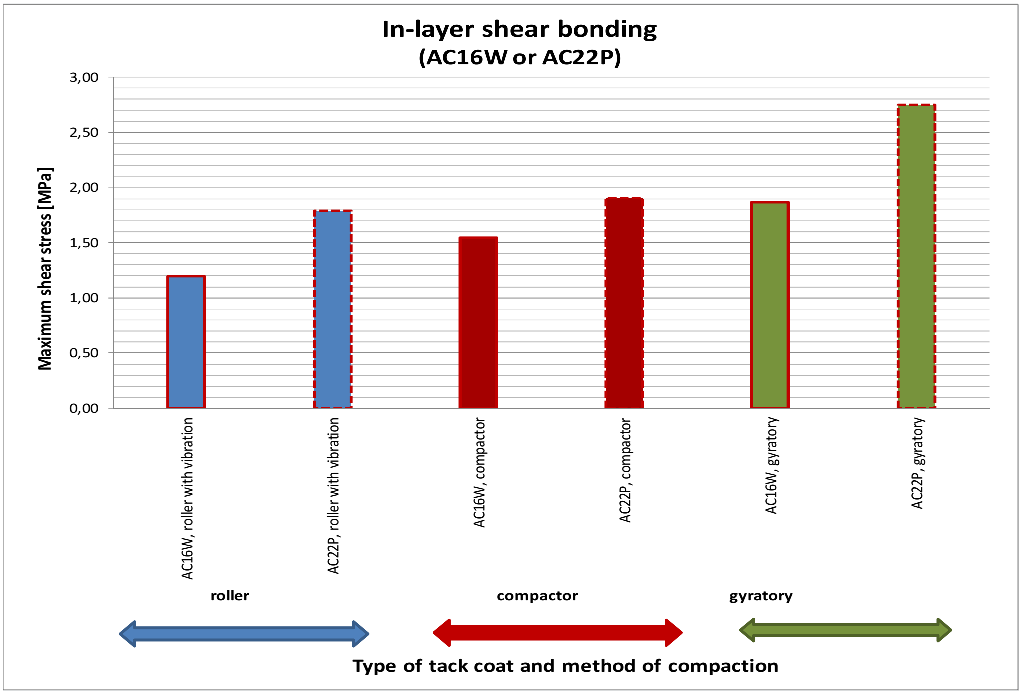


Fig. 4. In-layer maximum shear stress depending on compaction technique used in laboratory conditions

Fig. 5 presents the bond strength between wearing and binder courses measured in the tests carried out in 2006 on specimens produced with the use of three different tack coats and with two compaction techniques used both in laboratory and in field conditions. Two of the tack coats were made of bitumen emulsions. Obtained results confirmed the observations made in the tests mentioned before, i.e. very good effect of vibrations and spraying with bitumen emulsion on the interlayer bond quality. Also the type of tack coat was found to be highly relevant. The bond strength obtained with Type 2 emulsion made with 70/100 hard plain bitumen was much higher than in the case of Type 1 emulsion made with 160/200 soft plain bitumen. For all the compaction techniques lower bond strength was measured on specimens produced with the use of type 1 emulsion as compared to the specimens made with no tack coat at all. This is attributed to excessive difference in hardness between the bitumen of the tack coat (160/200) and of the asphalt layers (35/50). The low-viscosity tack coat bitumen is responsible for decreased stiffness and shear strength of the interface between the layers produced with harder bitumen. In this case the tack coat weakens rather than improves the multi-layer system behaviour in a way which decreases its service life.

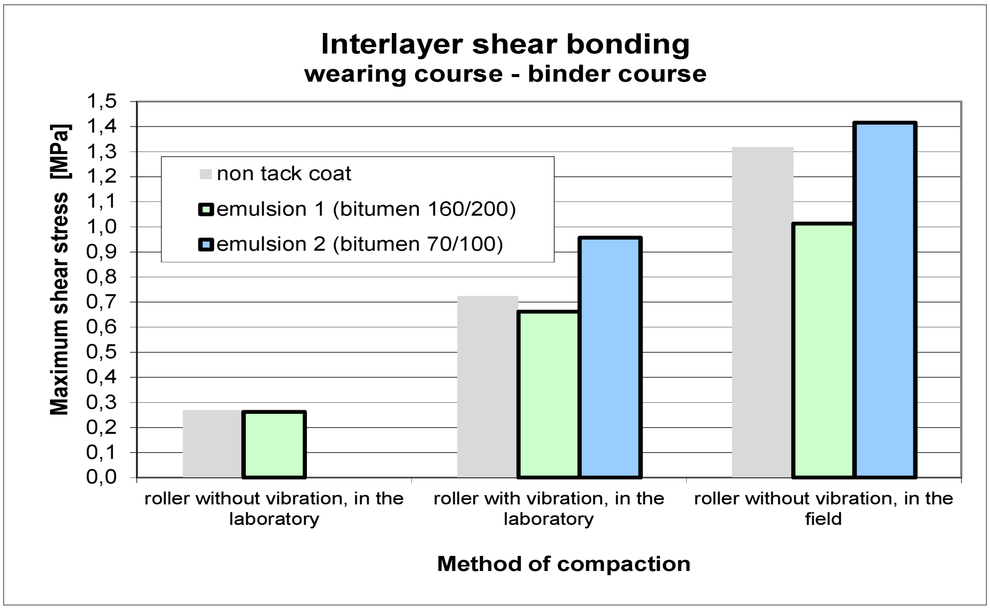


Fig. 5. Maximum interlayer shear stress for different types of tack coat and compaction techniques applied in the laboratory and in the field conditions

The most effective compaction method of the upper layer and the associated improvement of the interlayer bonding in the natural scale tests in comparison with the laboratory compaction was noted on the trial section installed during road reconstruction works.

Fig. 6 presents the bond strength values as a function of the degree of compaction of the upper asphalt layer. Results were obtained in direct shear tests conducted in the years 2012-2013 on specimens that were cut out from the newly constructed pavements. As it can be figured out from the chart, there is strong correlation between the wearing/ binder course bond strength defined by the maximum reliable shear stress values and the degree of compaction of the upper layer. This corresponds to the trend which were observed in evaluation of the binder/base course bond strength [13].

Thus it can be concluded that better compaction of the upper layer improves the aggregate interlocking between the upper and lower layers, which results in increasing of their bond strength.

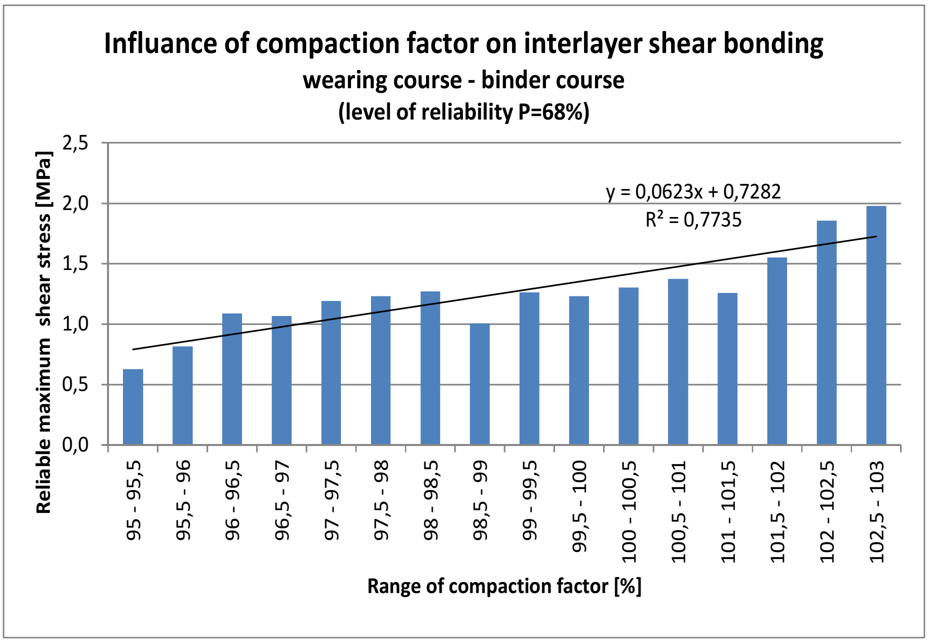


Fig. 6. Reliable maximum shear stress as a function of the degree of compaction of the upper layer

The reliable maximum shear stress values depending on the significance level were calculated for the respective ranges of the degree of compaction with the following Eqn. (1):

$$\tau_R = \tau - \alpha * \sigma \quad (1)$$

where: τ_R – reliable maximum shear stress, MPa; τ – average maximum shear stress, MPa; σ – standard deviation of the maximum shear stress, MPa; α – factor depending on the significance level P, for P = 68% α = 1.

5. Conclusions

On the basis of the test results obtained from testing of laboratory and field specimens it can be concluded that:

- The bond performance, defined as the maximum shear stress, strongly depends on the compaction technique used in laboratory conditions. The highest bond strength values were obtained for gyratory compaction and the lowest for compaction with a static roller. Laboratory roller compactor and vibrating roller gave similar quality of interlayer bonding.
- The compaction technique used in the laboratory for investigation of the bond strength is important in evaluating of the different tests results, where the bond strength value can vary up to 100%.
- The bond strength tests carried out on cores that were cut out from the pavements presented a strong relationship between interlayer bonding of asphalt layers and quality of compaction of the upper layer. Bonding was defined by the reliable maximum shear stress.
- The type of tack coat was found to be relevant to the quality of interlayer bonding. Bitumen emulsion dedicated for tack coat application (made from harder 70/100 plain bitumen) improves the bond quality, as compared to the interfaces without tack coat and with tack coat made with the inappropriate emulsion made from soft 160/200 plain bitumen.
- Inappropriate tack coat material, i.e. emulsion made from soft 160/200 plain bitumen resulted in lower bond quality as compared to configurations without a tack coat between the asphalt layers.

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