An investigation into the effects of tack coat application rate on interlayer shear bond strength

Rabbira Saba[1], Wenche Hovin[2], Torbjørn Jørgensen[1]

[1] *Road Technology, Norwegian Public Roads Administration, Trondheim, Norway*
[2] *Central laboratory, Norwegian Public Roads Administration, Trondheim, Norway*

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ABSTRACT

As part of a research and development project which aimed at improving the service life of pavements and which was conducted by the Norwegian Public Roads Administration, an investigation was conducted into interlayer bond strength. The purposes of the investigation were to find out if the current requirements regarding tack coat are satisfactory and to determine appropriate bond strength values that can be used as basis for improved requirements. The work involved both field and laboratory testing in which first measurements of tack coat application rates on normal paving projects were conducted and analysed. Then varying quantities of tack coat, with three targeted levels, were applied on selected test roads with two texture levels. The amount of applied tack coat was measured and after completion of the paving, core samples with 100 mm in diameter were taken from the test roads. The samples were tested in shear bond test (SBT) in accordance to prEN 12697 -48. The results from this study indicated that the effect of the quantity of tack coat depends on the surface characteristics of the underlying layer. For smooth surfaces increasing application rate resulted in decreasing shear bond strength. For rough surfaces, the results indicated little or no correlation between tack coat application rate and shear bond strength.

Keywords: Adhesion, Bonding, Emulsions, Surface Texture, Tack coats

1. INTRODUCTION

Poor bond between asphalt pavement layers is a cause of pavement distress. The most common distress caused by poor bond is the slippage failure, which usually occurs at areas of deceleration and acceleration. The slippage is thought to be the result of horizontal forces exceeding the shear strength of the interlayer bond. Other types of pavement distresses including premature fatigue, surface layer delamination and top down cracking are also attributed to poor bond between asphalt layers [1, 2, 3].The cause of asphalt blisters, which sometimes arise during warm weather, is also considered to be poor bonding conditions between the asphalt layers.

Bonding condition between pavement layers can also affect the stresses, strains, and deflections that develop under load. Hariyadi et al [4] conducted a theoretical study of the effect of bonding condition between pavement layers on strain response using the BISAR software. The bonding conditions considered in the analysis ranged from weak bonding to strong bonding and included partial bonding. The authors concluded that better bond between pavement layers results in decrease in strains, which in turn increases the structural capacity of the pavement structure.

Sutanto [5] provided an excellent review of theoretical studies that focused on the analysis of the effect of bonding conditions on the stresses and strains in the pavement structure and consequently on the performance of pavements. These studies showed that the bonding conditions have very significant effect on the stresses, strains, and deflections and can therefore have an influence on the design and performance of the pavements.

The strength of the bond between two asphalt layers is affected by a number of factors including the amount of tack coat, the type of emulsion, the uniformity of tack coat application, texture of the contacting layers, cleanness of the contact surface, temperature and loading [2, 3, 6]. Because such a large number of factors affects the bond strength, it is often difficult to isolate and characterize the effect of few of these factors. The interlayer bond strength is thought to have three components: adhesion, mutual interlocking of stone aggregates at the surface, and friction. A number of studies, which looked at the effect of emulsion type and application rates, have been reported in the literature. The objective for most of these studies was to find optimum application rates.

Mohammad et al [6] reported on a comprehensive study, which was conducted under the National Cooperative Highway Research Program (NCHRP) in the USA. The objectives of the study were to find out optimum application rates, optimum methods of application, and to develop appropriate methods for testing of the bond strength between layers and the quality of application. The work involved both laboratory and field investigations in which five types of tack coat emulsions and three levels of application rates were considered. The underlying layers considered in the study included old asphalt pavement, milled asphalt pavement, new asphalt pavement, and grooved concrete pavement. The results of the study showed that there is a direct correlation between the bond strength and texture of the underlying layers. Milled surface had the highest bond strength values followed by grooved concrete pavement, old asphalt pavement and new asphalt pavement. The authors, therefore, provided recommended application rates based on the type of underlying layers. The results also showed that laboratory made samples had higher measured bond strength values than field samples. Higher application rates resulted in lower bond strength for laboratory made samples while it resulted in higher bond strength values for field samples.

West et al[1] conducted an extensive laboratory and field study of tack coat materials and bond strength between pavement layers. The objectives of the study were to develop a test method for evaluation of bond strength between pavement layers and to provide information that enables selection of the best tack coat materials. The study focused on evaluation of the effects of application rate, type of tack coat material, type of asphalt mixture, test temperature, and lateral load on the bond strength using shear bond strength test. The authors concluded that all the investigated factors had a statistically significant effect on the bond strength, but temperature had the greatest effect clearly indicating the higher the temperature the lower the bond strength. The results from the study showed that lower application rates result in higher bond strength values and the bond strength depends on the maximum aggregate size of the mixes.

One of the problems regarding tack coat that is often encountered during paving is tracking (pick up) by paving truck tires. To overcome this problem, special emulsions called trackless emulsions have been developed and marketed. Trackless emulsions are reported to break very fast thus enabling the avoidance of tracking. Few authors have evaluated the performance of trackless emulsions in comparison to commonly used bitumen emulsions. Clarke et al[7] reported on a laboratory investigation conducted to evaluate the performance of trackless emulsions in which five trackless emulsions were compared to a commonly used rapid setting emulsion. The authors concluded that trackless emulsions had higher bond strength values but also higher standard deviation compared to the rapid setting emulsion. Chen et al [8] reported on a study conducted to evaluate the effect of trackless emulsion on the resistance to top –down cracking of asphalt layers. The conclusion from this study was that the trackless emulsion resulted in better resistance to top-down cracking compared to a commonly used rapid setting emulsion.

Several test methods and procedures have been developed to determine the bond strength between pavement layers and have been evaluated by several authors [1, 5, 6, 9, 10]. These include shear bond strength test, tensile test, and torsion test. Of these test methods, the shear bond strength test is the most widely used because of its simplicity.

One can observe from the literature that the importance of tack coat for pavement performance is being recognized and a number of studies have been conducted to evaluate bond strength between pavement layers under various conditions. However, when it comes to the effect of the major factors such as application rate and surface texture, differing results have been obtained. Thus it appears that there is a need for further research to evaluate the effect of these factors. The study reported in this paper focuses on evaluation of the effect of application rate and the texture of the underlying layer.

The purposes of the study reported herein are to find out if the current requirements regarding tack coat are satisfactory and to determine appropriate bond strength values that can be used as basis for improved requirements. The study was part of a research and development program called "Durable Roads" which was conducted by the Norwegian Public Roads Administration. In Norway there is a requirement for tack coat application rate, which is a minimum of 0.3kg emulsion per square meter, but there is no standardized method for checking the actual quantities applied in the field during paving. There is also a question on whether having a single requirement for all types of surfaces (new, old, milled) is right or not.

The work involved both field and laboratory testing in which first a measurement of the quantities of tack coat on normal paving projects were conducted and analysed. Then varying quantities of tack coat, with three targeted application rates, were applied on selected test roads with different texture levels. The amount of applied tack coat was measured and after completion of the paving, core samples with 100 mm in diameter were taken from the test roads. The samples were tested in shear bond test (SBT) in accordance to prEN 12697-48[11]. Currently there is no CEN test method for determination of the quantity of tack coat applied during paving. A simple method was developed and used in this study to measure quantities of the applied tack coat. The subsequent chapters of this paper describe the methods used, the results obtained, and the conclusions drawn based on this study.

2. MATERIALS AND METHODS

Several paving projects were considered in this investigation. The underlying layers varied; some are new (new binder layers), and some are old asphalt surfaces. Thus their texture varied significantly. The tack coat materials used in this study were designated as follows to maintain the anonymity of the contractors.

- BE–1: rapid setting bitumen emulsion with additive
- BE–2: rapid setting bitumen emulsion
- BE-3: medium setting bitumen emulsion

2.1 Measurement of Application Rates

The first part of the work, which was conducted in 2013, involved development of a method for determination of the quantity of tack coat that was applied during paving. As there is currently no standardized European method for determination of application rate, a simple method was developed based on ASTM (American Society for Testing and Materials) D2995 [12]. The method involves placing a sheet of known area and weight on top of the pavement. After application of the tack coat, the sheet is removed and weighed to determine the amount of tack coat sprayed on the area. In this study materials such as cardboard, paper, and textile fibre were tried at first to see if they are suitable materials. Figure 1 shows a picture of one of the trials. It was found out that the textile fibre is most suitable for determining both the quantities of emulsion and the residual binder and therefore it was selected. A sheet of textile fibre with dimension of about 25cm X 35cm was used for determination of the application rate.

The measurements of the application rates were conducted as follows:

1. For determination of the residual binder, the sheets were put in an aluminium box and pre-weighed in the laboratory. For determination of total amount of emulsion, the sheets were put in a plastic bag and pre-weighed.
2. The sheets were attached to the pavement surface using duct tape, one at each corner on the underside of the sheets. The sheets were placed in such a way that they will lie between the wheels of the tack coat truck.
3. After spraying of the tack coat, the sheets were carefully removed and put back in the aluminium box. For determination of the total amount of emulsion, the sheets were carefully folded, put in a plastic bag and sealed.
4. The sheets that were used for determination of residual binder were dried in the laboratory at 140 ºC for 30 minutes before reweighing. The sheets that were used for determination of total emulsion were reweighed in the sealed plastic bag within a short period of time (maximum of two hours).
5. The application rates were calculated as the weight of residual binder or emulsion divided by the area of the sheet.

Figure 1: Trials for measurement of tack coat application rates

2.2 Measurement of Shear Bond Strength

Asphalt specimens with a diameter of 100mm were taken from the test sites few weeks after completion of paving. Specimens were taken both from the wheel path and between wheel paths. The driving direction was marked on the specimens. For five of the test sections, specimens were taken from the whole width of the lane to see lateral variation of shear bond strength. Three parallel specimens were taken from each section.

The tests were conducted using Marshal apparatus in accordance to the draft European standard prEN 12697 – 48. The specimens were stored in room temperature and were conditioned at 20±1ºC for at least 16 hours before testing. After conditioning the test specimen was fastened to the apparatus as shown in figure 2. A direct shear force was then applied at a shear rate of 50±2 mm/minute parallel to the driving direction and the developments of shear deformation and force were recorded. No confining pressure (normal load) was applied. The maximum shear stress obtained is the interlayer shear bond strength.

Figure 2: Shear bond strength test equipment and specimen.

3. RESULTS AND DISCUSSION

This section presents and discusses the results obtained during this investigation.

Figure 3 shows results from measurement of the application rates that was conducted in 2013 to check if the requirement of minimum 0.3kg emulsion per square meter is met. Nine test sections were involved in this investigation. As it can be seen in figure 3, none of the tested paving projects satisfied this requirements and many are far below the requirement. It was also observed that it was difficult to measure the application rate in terms of the total emulsion quantity, as some of the water was lost during spraying. It was therefore decided to base the requirement on the residual binder rather than emulsion and the requirement was accordingly changed to minimum 0.15 kg residual binder per square meter.

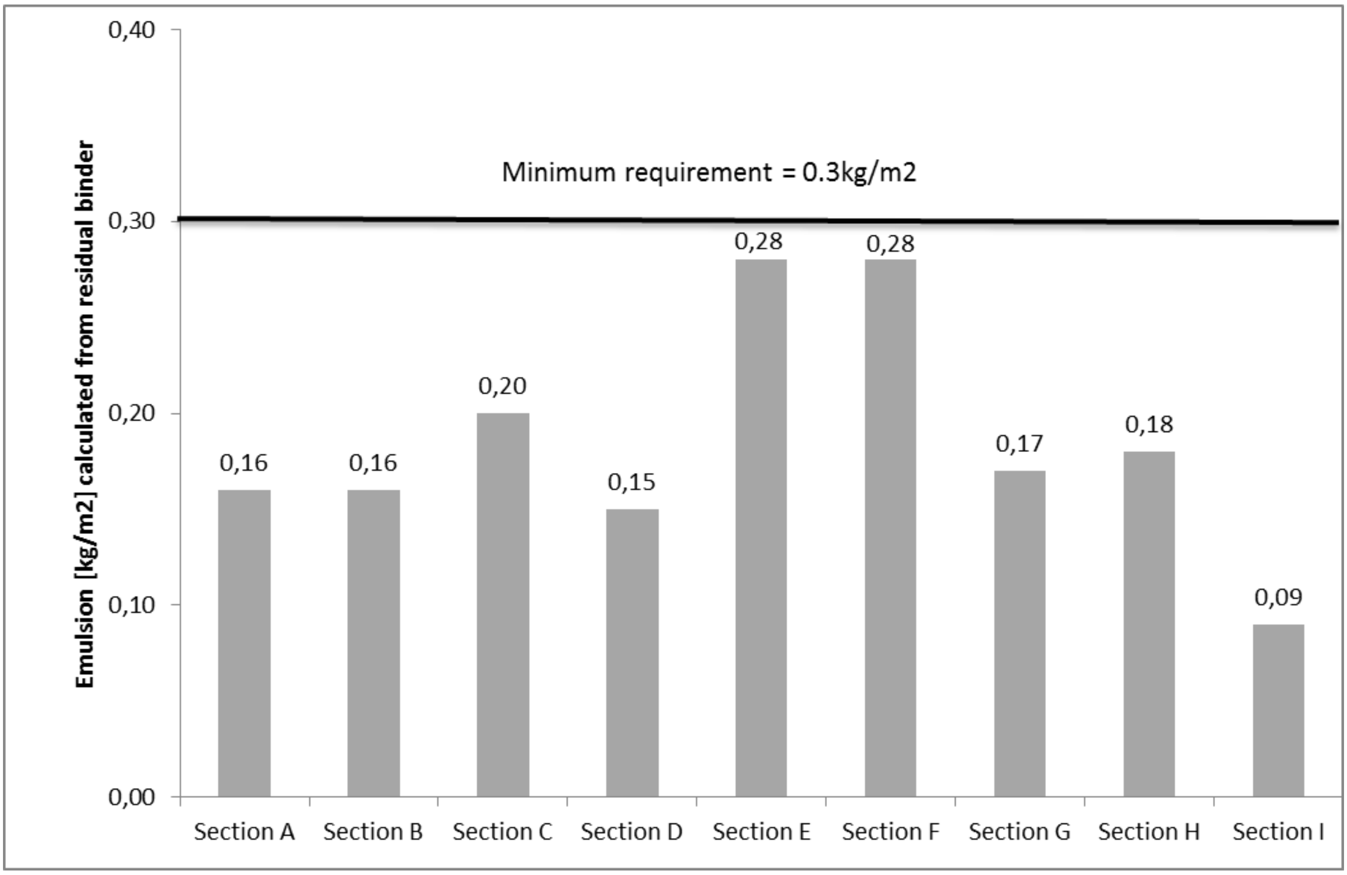

Figure 3: Measured application rates

Specimens were taken from six of these sections and shear bond strength testing was conducted. Figure 4 shows the measured bond strength values for specimens taken from wheel paths and between wheel paths as well as the standard deviations. The standard deviations are generally small indicating good repeatability of the test. Sections B and E had a medium setting emulsion (BE-3) while the rest of the sections had rapid setting emulsion (BE-1). Emulsion was applied on a new binder layer for all sections but section B, where it was applied on old pavement.

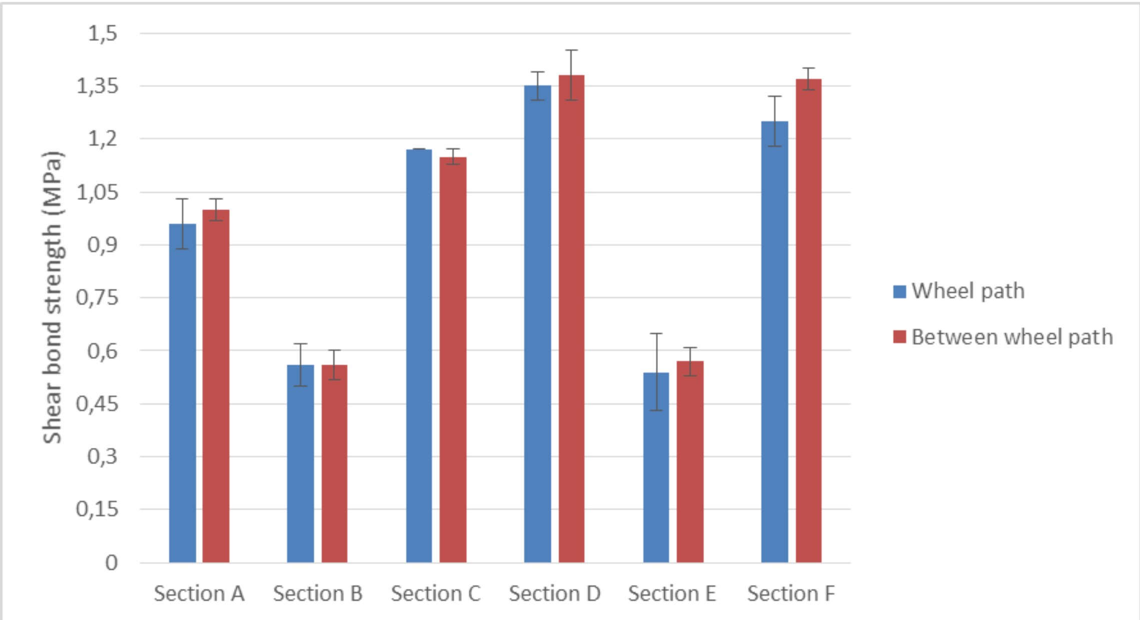

Figure 4: Measured shear bond strength

As can be seen from figure 4, there is no significant difference in shear bond strength between wheel path specimens and those from between wheel paths, with exception of section F. Although the application rates were far below required minimum, as shown in figure 3, the measured shear bond strength values are relatively high for four of the six sections. There is currently no minimum bond strength requirement in Norway, but compared to the Swiss requirement of 0.85 MPa, for instance, the four sections can be considered to have acceptable bond strength values. There also appears to be no correlation between the application rates and the bond strength values as shown in figure 5, but this can be due to differences in the underlying layers. A closer look at the two sections with low shear bond strength shows that they both had a medium setting bitumen emulsion. It was also observed that section B was paved on an old dusty pavement and section E had warm mix asphalt paved, under light rain, on a newly laid warm mix asphalt layer. This suggests that a combination of relatively slow setting emulsion, lack of cleanness, paving at lower temperature and under rainy weather may have created a condition for poor bond between layers.

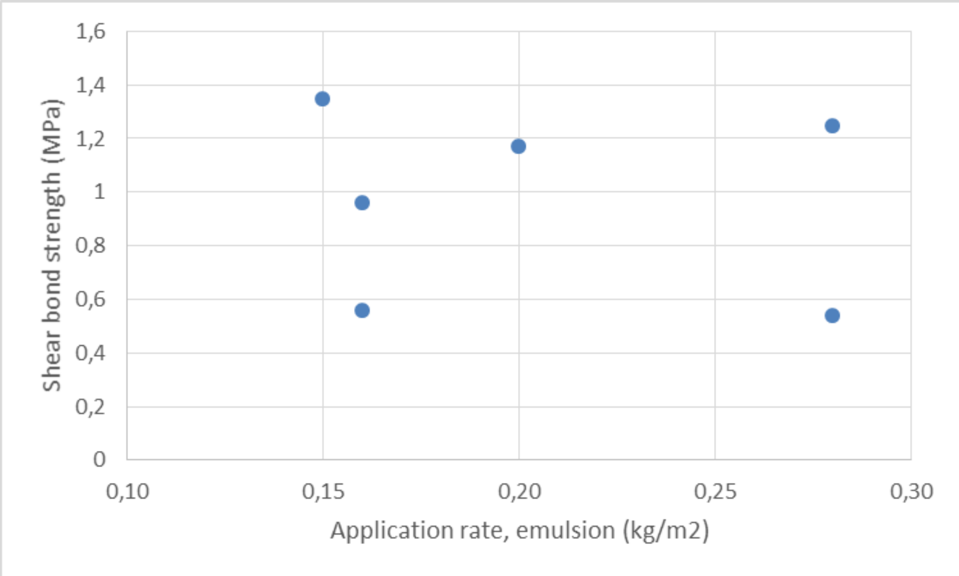

Figure 5: Correlation between application rates and shear bond strength

Since the results from 2013 showed that rather low application rates could result in higher shear bond strengths it was decided to investigate the effect of application rate on shear bond strength further with an experiment in which the application rate was varied on the same road section. Sections with different texture levels were also selected to see if the texture has a significant effect. This investigation was conducted during the 2014 paving season. Three application rates; 0.075, 0.15, 0.225 kg/m^2 in terms of residual binder were targeted. These rates represent the current minimum requirement (0.15kg/m^2), 50 % under the requirement (0.075kg/m^2) and 50% over the requirement (0.225kg/m^2). Although the contractors made an effort to adjust their equipment and apply the targeted amount, the measured application rates differed from the targeted values. The investigation included four test sections where two rapid setting emulsion types, BE-1 and BE–2 were employed. Each test section was divided into three sub-sections corresponding to three targeted application rates, which gave a total of twelve sub-sections.

Shear bond strength testing was conducted on core specimens taken from these sections. Cores were taken both from the wheel paths and between wheel paths. Six core specimens (three in the wheel path and three between wheel paths) were taken corresponding to each targeted application rate. To analyse the result in relation to texture, surfaces with texture less than 1mm were classified as smooth and those with texture over 1 mm were classified as rough. Two of the four sections have less than 1mm texture depth and thus are considered smooth while the other two are rough.

Figure 6 shows the effect of application rate for the smooth surfaces and figure 7 shows that for rough surfaces. Each data point on these figures represent an average bond strength for three specimens and include the two emulsion types BE – 1 and BE-2. These two emulsions are both rapid setting and similar in character. As can be seen from figure 6, for smooth surfaces, increasing application rates resulted in decreasing shear bond strength. This in part agrees with the findings of others [1, 6]. For smooth textured surfaces, higher quantities of tack coat may reduce the contribution from the mutual interlock of aggregates at the contact surface and thus may result in lower shear bond strength values. For rough surfaces, however, the correlation between application rate and shear bond strength is weak for wheel path data and non-existent for data from between wheel paths as indicated by very low R^2 values (figure 7). This is a surprising result as one would expect increasing shear bond strength with increasing application rate for these surfaces. However, the reason for this result might be, for the range of application rates tested in this investigation, the effect of mutual interlock of aggregates might be so dominant that the results could not reflect the effect of the application rate. As previously noted interlayer bond strength depends both on mutual interlocking of aggregates at the surface and adhesion. In this case, it appears that the effect of adhesion is relatively small compared to that of mutual interlock of aggregates. This may raise questions regarding the suitability of the shear bond test method for study of the effect of the application rate. Had one used a tensile test instead of the shear bond test, the results might reflect the effect of application rate. One therefore should conduct similar study using tensile test to be able to draw conclusions regarding the effect of application rate. However, comparison of these test methods is beyond the scope of this study.

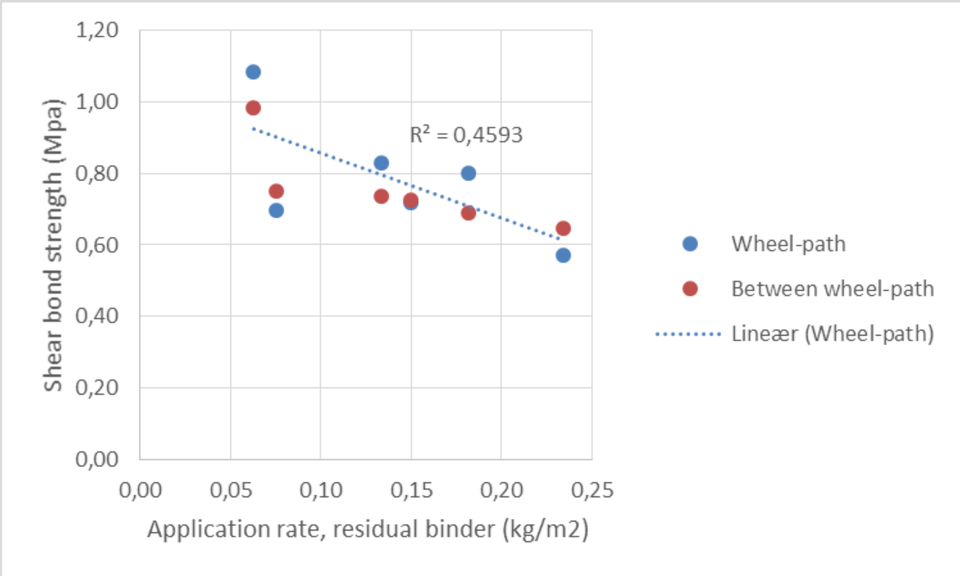

Figure 6: Correlation between application rate and shear bond strength for smooth texture

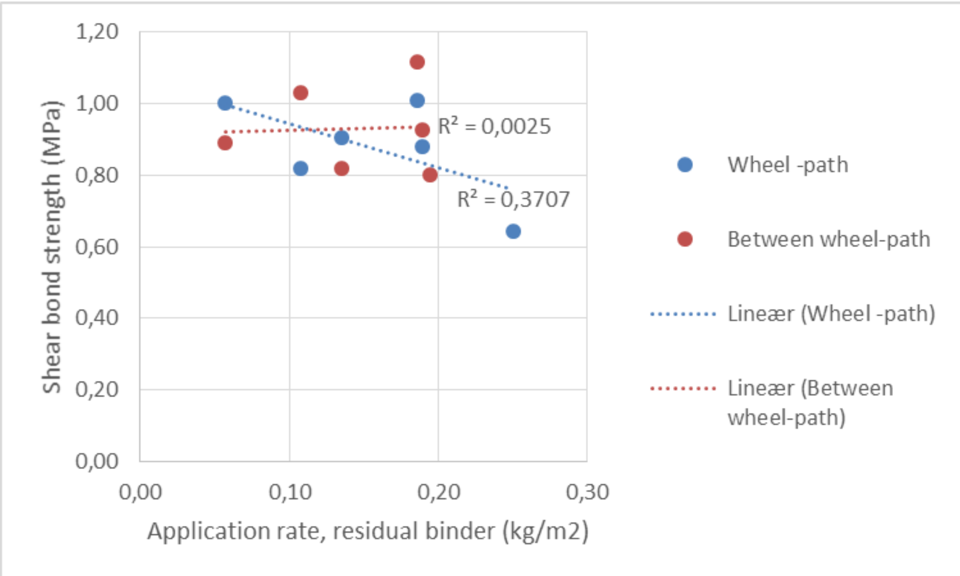

Figure 7: Correlation between application rate and shear bond strength for rough texture

Figure 8 shows data for all sub-sections (smooth and rough) put together. Here again one can see weak or no correlation between the application rate and shear bond strength.

Figure 9 shows average shear bond strength values on smooth and rough surfaces. The average shear bond strengths on rough surfaces are larger than that on smooth surfaces but the difference is not statistically significant. To see how the bond strength change with time, core specimens where taken in 2014 from two of the sections tested in 2013. The result is depicted in figure 10 for two emulsion types BE – 1 and BE – 3 and it shows that the bond strength tends to increase after one year of traffic loading. This most likely is due to compaction under traffic, which creates more interlock at the contact surface.

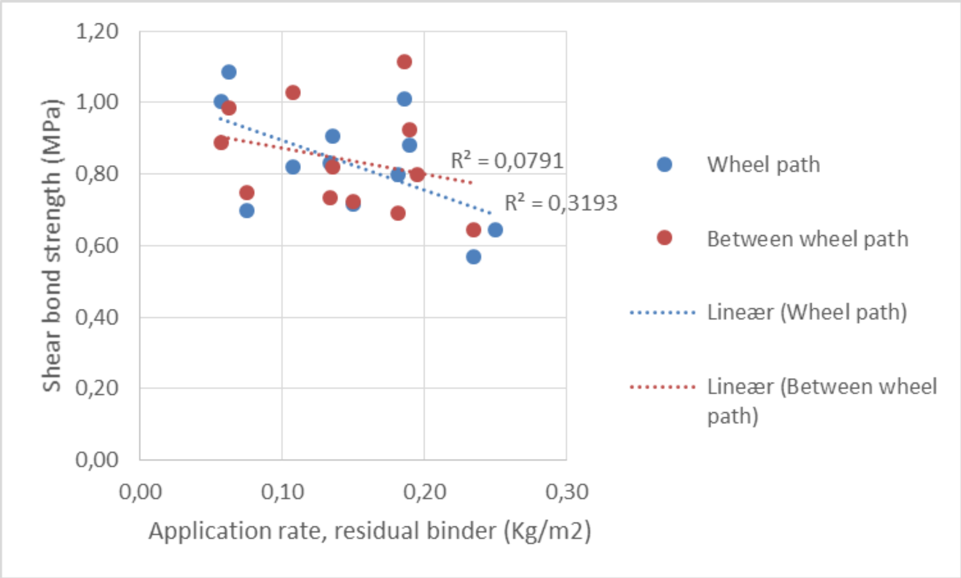

Figure 8: Correlation between application rate and shear bond strength for all sections

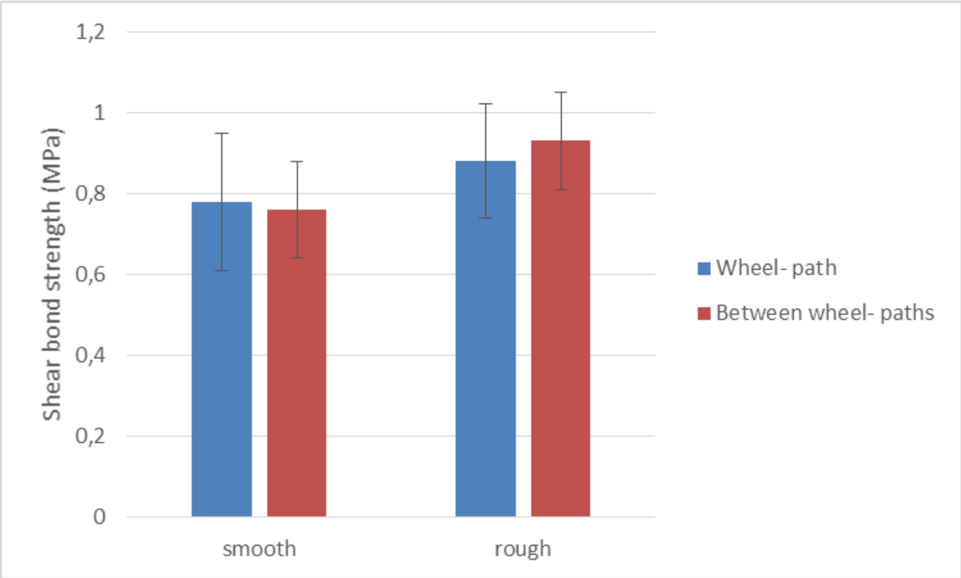

Figure 9: Comparison of shear bond strength on smooth and rough surfaces

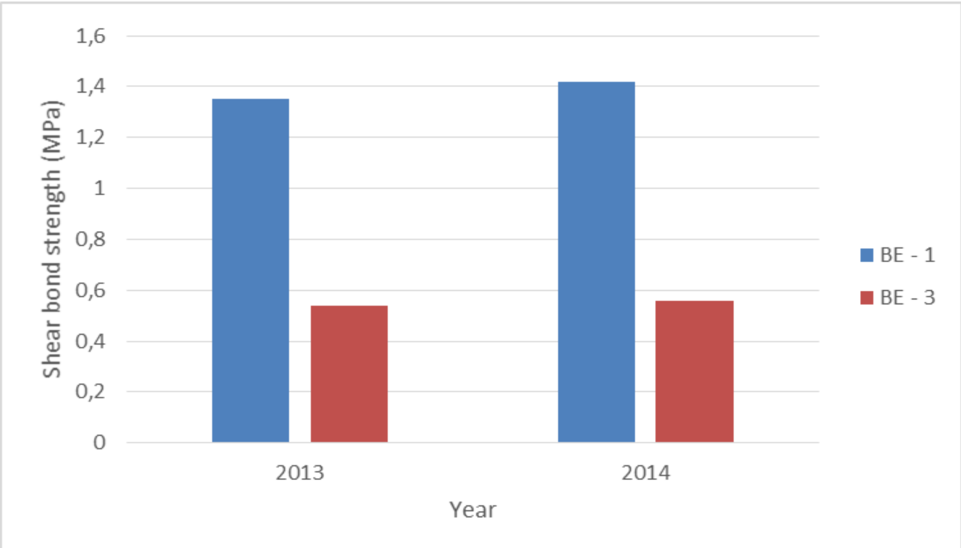

Figure 10: Effect of traffic (compaction) on shear bond strength

4. CONCLUSIONS AND RECOMMENDATIONS

Results of an investigation conducted to study the effects of tack coat application rate on shear bond strength for asphalt surfaces with varying texture levels are reported in this paper. The objective of the study was to find out bond strength values that can form basis for improved requirements. The results of the study showed that:

1. For smooth surfaces with texture depth of less that 1mm, increasing tack coat application rate resulted in decreasing shear bond strength.
2. For rough surfaces with texture depth of over 1mm, weak or no correlation between application rate and shear bond strength could be found. In general, when results for smooth and rough surfaces are put together, there is a weak negative correlation between application rate and shear bond strength for data from wheel paths and no correlation between application rate and shear bond strength for data from between wheel paths.
3. Average shear bond strength values for rough surfaces are higher than those for smooth surfaces but the difference is not statistically significant.
4. Shear bond strength values increased slightly after one year of traffic loading.

However, this study is quite limited in extent to be able to draw firm conclusions with regard to effect of application rate. This is because other influencing factors such as the cleanness of the surfaces were not considered in this study. The number of test sections involved as well as the range of variation of the application rate for some of the sections are also limited. The study, however, can serve as a good pointer for designing further experiments to analyse application rates in relation to interlayer bond strength. It is therefore recommended to continue the study considering a wider range of surfaces as well as other test methods such as the tensile test for analysis of the effect of application rate.

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REFERENCES

[1] Evaluation of bond strength between pavement layers, West R. C., Zhang, J. & Moore, J. NCAT report 05 -08, 2005.

[2] Tack coat optimization for HMA overlays: Laboratory testing, Al-Qadi, I.L., Carpenter, S.H., Leng, Z. & Ozer, H., Illinois center for transportation series no. 08 – 023, 2008

[3] Effect of tack and prime coats, and baghouse fines on composite asphalt pavements, Kulkarni, M.B., PhD thesis, North Carolina State University, 2004.

[4] Theoretical study of bonding conditions at the interface between asphalt pavement layers, Hariyadi, E.S., Aurum, K.P. & Subagio B.S, Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 9, 2013.

[5] Assesment of bond between asphalt layers, Sutanto, M.H., PhD thesis submitted to the University of Nottingham, 2009.

[6] Optimization of tack coat for HMA placement, Mohamad, N.L., Elseifi, M.A., Bae, A., Patel, N., Button, J., & Scherocman, J.A., NCHRP report 712, 2012.

[7] Trackless Tack Coat Materials – A Laboratory Evaluation for Performance Acceptance, Clark, T.M., Rorrer, T.M., & McGhee, K.K., TRB annual meeting CD – ROM, 2010

[8] Effects Of Trackless Tack Interface On Pavement Top-Down Cracking Performance, Chen, Y., Tebaldi, G., Roque, R., & Lopp, G., Procedia - Social and Behavioral Sciences 53 (2012) 432 – 439, SIIV - 5th International Congress - Sustainability of Road Infrastructures, 2012.

[9] Effect of tack coats on interlayer shear bond of pavements, Raab, C. & Partl, M. N.,Proceedings of the 8th conference on asphalt pavements for Sothern Africa, 2004

[10] Evaluation of interlayer shear bond devices for asphalt pavements, Raab, C., Partl, M.N., Halim, Abd El Halim Omar Abd El, The Baltic Journal of Road and Bridge Engineering, Vilnus Gediminas Technical University, 2009, available on http://www.thefreelibrary.com.

[11] prEN 12697-48, Bituminous Mixtures – Test Methods for Hot Mix Asphalt- Part 48: Interlayer Bonding, European Committee for Standardisation

[12] ASTM D2995 – 99 (2009), Standard Practice for Estimating Application Rates for Bituminous Distributors, American Society for Testing and Materials.