Asphalt mixture performance and testing

Investigation of Interlayer Bond Strength Using Tensile and Shear Tests

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Abstract

Bond between asphalt layers is an important factor for performance of asphalt pavements. The interlayer bond strength depends on many factors including type of tack coat, application rate, type of surface, and temperature. This paper reports on an investigation conducted using modified emulsions on two paving projects. Each project was divided into three test sections. Three levels of application rates were used on one of the paving projects while two application rates were used on the other resulting in five test sections. Core specimens were taken from each of the sections and tested using tensile and shear bond strength testing methods. Results from these tests were analysed to investigate the effects of application rate on bond strength. Results of an earlier study, which was based on unmodified emulsions and shear bond testing, were reanalysed and used in addition to data obtained from the current study to investigate the relationship between shear bond strength and application rate for different surface types. The result of this analysis showed that there is no correlation between application rate and interlayer bond strength with in the ranges of application rates considered in this study.

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1. INTRODUCTION

Flexible pavements are structures composed of layers of different materials that are assumed to be bonded at the interfaces. In structural design of these pavements one usually assumes that the layers are fully bonded and act as monolithic structure. However, in practice, this is not always the case since poor interlayer bond and debonding of interfaces are observed. Tack coats are applied during pavement construction to ensure bonding between the layers. Bituminous emulsions are the most widely used tack coat materials. This is due to the low viscosity of bituminous emulsions which makes it easy to spread at ambient temperature. Penetration grade (or performance grade) bitumen binder has also been used as tack coat material. Some modified tack coat materials (with various additives) have also become available on the market in recent years.

Performance of layered flexible pavements depend on the bond between the individual layers. Poor interlayer bond can lead to premature distresses such as slippage cracking, fatigue cracking, corrugations, etc. Poor interlayer bond can also severely affect the structural capacity of the pavement. It is therefore essential that the interlayer bond strength between the pavement layers is enough to withstand the stresses to which the interface is subjected.

The importance of interlayer bond for pavement performance has been recognized. Several researches have been conducted in the last decade to study various aspects of interlayer bond [1, 2, 3, 4]. Most of these research works have used different test methods and materials and have come to differing conclusions. The interlayer bond strength is expected to be influenced by several factors including the type and texture of the surfaces, the tack coat material properties, the application rate, cleanness of the surface, and temperature and moisture conditions. Some researchers, however, have obtained some unexpected results like the bond strength of interfaces without tack coat being higher than those with tack coats. Excessive tack coat may weaken the interface by introducing a slippage plane while too little tack coat may result in unsatisfactory bond strength at the interface. It is therefore very important to determine the optimum application rate that ensures the necessary bond strength.

Despite the recognition of the importance of interlayer bond for pavement performance, there is so far no consensus when it comes to the testing method. Failure of interlayer bond can occur due to shear, tension or torsion. Pavement interfaces are subjected to complex vertical, horizontal and shear stresses. Therefore, several researchers have come up with various test methods.

The test methods that have been developed over the years can be classified into three; shear, tensile and torsional tests. Shear tests attempt to simulate debonding or interface damage caused by shear loading. Various shear test equipment have been developed in many countries. The shear tests are conducted either in pure direct shear loading (without normal stress) or direct shear loading with normal stress. Direct shear tests are conducted on cylindrical specimens, either cored from field or produced in the lab, with diameter of 150mm or 100mm. One obtains a graph of the shear force vs displacement from the shear tests, which allows the calculation of maximum shear stress, the shear stiffness modulus, and shear bond energy [4]. Pure direct shear tests are relatively simple to conduct and are used by many road agencies. However, these tests might not capture the effect of complex loading situation that in reality happens at the interface.

Tensile tests attempt to simulate interface damage caused by tensile loading. Two main type of tensile loading devices have been developed [4]; Tensile Bond Test (TBT) without notch and Tensile Notch Bond Tests (TNBT). The devises differ in specimen geometry, tensile load application rate and the mechanism by which the specimens are held. TBT can be conducted either in the field or in the lab. The geometry of the test specimens makes it difficult to get uniform and pure tensile stress loading in tensile tests, which is considered a drawback.

Torsional tests allow measurement of torsional bond at the interface. Torsional test devices are comprised of a gripper system that is glued to the specimen and a cell that applies torque. Torsional tests can be conducted either in the field or in the laboratory. Torsional tests create non-uniform stress distribution varying from zero at the centre of the interface cross-section to a maximum value at edge. Torsional test devices can also induce shear stresses in the surface course of the specimen, and hence considered to be less precise and more difficult to interpret compared to direct shear tests [4]
Some researchers have proposed advanced tests that combine the tensile and shear modes of loading. However, these tests are complex and time consuming that it is unlikely they will be used for quality control purposes.

One of the challenges that road agencies face is the determination of optimum tack coat application rate for a given surface type/interface. Different testing methods seem to give different optimum application rate. The relationship between application rate and bond strength is unclear [5]. There is also a question of at which environmental conditions (temperature and moisture) should the optimum application rate be determined. Khoee [6] compared optimum application rate as obtained from direct shear bond testing and torsional shear testing to that obtained from tensile type testing called Interface Bond Test (IBT). IBT uses a notched specimen and applies tensile stress to induce crack opening at the interface. The IBT test was conducted at -12ºC, while the direct shear and torsional shear tests were conducted at 25ºC and 22ºC respectively. The result showed that the optimum application rate obtained from the IBT was approximately twice those obtained from direct shear and torsional shear tests. This indicates that the optimum application rate depends on the mode of testing and the temperature at which the test is conducted.

From road owner's point of view, it is important to set appropriate requirements and to have a standardized test method for quality control of finished pavements. Most road agencies have set requirements based on the application rate of tack coat emulsion, only few agencies have set requirements based on bond strength. The requirement for application rate and the choice of tack material type are generally based on experience and judgment rather than an objective measurement. While application rate is relatively easy to measure and verify, it might not ensure adequate bond strength because the bond strength is affected by, among other factors, the uptake (tracking) by paving truck tires and cleanness of the surface. There is therefore a need for an objective test method that can be used in quality control of the interlayer bond strength of the finished pavements.

The Norwegian Public Roads Administration (NPRA) has previously conducted some investigation into interlayer bond strength with focus on the relationship between application rate and interlayer bond strength as measured in shear bond testing [5]. There results of the investigation showed that there is week or no correlation between the application rate and the measured shear bond strength. This has raised several questions including:

1. Is the test method (direct shear bond testing) the right method to measure the adhesive bond between the layers, i.e, to evaluate the effect of the applied tack coat?
2. Would the tensile test method be more appropriate?
3. Are the test methods capable of measuring the effect of the quality of the emulsion (effect of modified emulsion as opposed to ordinary emulsion for example)?
4. What is the appropriate level of bond strength to use in setting requirements?

The study reported in this paper is a contribution to the effort being made to answer some of these questions. Test sections were laid with varying application rate. Specimens cored from these test sections were tested in the laboratory using tensile and shear tests. In the following sections, the materials, the testing and the results of the testing are described and discussed.

2. MATERIALS AND METHODS

Test sections were laid in connection to two paving projects using modified tack coat emulsions. On one of the projects, SBS (Styrene - Butadiene – Styrene) modified emulsion was used, while on the other project a latex-modified emulsion was used. Three test sections corresponding to three application rates were laid in each project. The test sections were about 30 meters long. These sections are referred to in this paper as 1-1, 1-2, 1-3 and 2-1, 2-2, 2-3 for the two paving projects. In this paper the emulsions used are designated as follows corresponding to the paving projects 1, and 2:

- PMBE 1: latex modified
- PMBE 2: SBS modified

The underlying layer for paving project 1, where PMBE 1 was applied, is an old asphalt pavement, while the underlying layer for project 2 was a milled asphalt surface. The plan was to use three different application rates on each paving project to investigate the relationship between application rate and bond strength. Unfortunately, the lowest application rate was not used on project 2 due to equipment problems. Target application rates were 0.07, 0.14, and 0.21 kg/m^2 residual binder. The actual quantities of tack coat applied on each section were then measured after application.

2.1. Measurement of Quantities of Applied Tack Coat

The actual tack coat application rates were measured using a method that was developed earlier based on ASTM D2995. The method involves placing a sheet of textile fibre with 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. The textile fibre sheets had a dimension of 25cm X 35cm. Details of these method has been described in [5]. Two textile fibre sheets were used for each section.

2.2 Measurement of Shear Bond Strength

Testing for measurement of shear bond strength was conducted in accordance to the draft European standard prEN 12697 – 48[7]. Specimens with 100mm in diameter were cored from the test sections. Three parallel specimens were cored from between wheel path for each section. The driving direction was marked on the pavement before coring. The specimens were stored in room temperature and their diameter was measured before conditioning. The specimens were conditioned in a climate chamber at 20±1°C overnight and were tested next day. The test specimen was then fastened to the apparatus as shown in figure 1. The tests were conducted using a universal press, which is also used as Marshal apparatus. A direct shear force was 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 interlayer shear bond strength was determined from the maximum shear force and the cross-sectional area of the specimen. Observation of the interfaces after testing showed that failure occurred at the interface, i.e., the failure was an adhesive failure for all specimens.

Figure 1: Shear bond strength testing equipment and specimen

2.3 Measurement of Tensile Bond Strength

Tensile bond strength testing was conducted using a special test setup and equipment. Core specimens with diameter of 100mm were trimmed at the ends to obtain flat surfaces. Steel plates with 100mm in diameter were glued to the ends of the specimens. These steel plates were then fastened to the tensile test equipment. Figure 2 shows the tensile test equipment and the specimen. The specimen was then subjected to a tensile load at a rate of 200N/sec until failure. The testing was conducted at 20°C. Three parallel specimens were tested for each section. Failure occurred in the interface, i.e., adhesive failure, for all but one specimen(this one specimen was not used in the analysis). The tensile bond strength was calculated by dividing the tensile force at failure by the cross-sectional area of the specimen.

Figure 2: Tensile bond strength test equipment and specimen

3. RESULTS AND DISCUSSION

In this section results of measurements and tests conducted in this study are presented and discussed. Some data from previously conducted tests are also used in addition to the ones obtained during this study in an attempt to elucidate the relationship between tack coat application rate and interlayer bond strength.

3.1 Application Rate

The measured actual application rates together with the targeted application rates are shown in table 1. The actual applications rates are very close to the targeted application rates for all sections. As some of the applied tack coat will often be picked up (tracking) by paving vehicle tires, the real quantity of tack coat can significantly differ from the applied quantity.

Table 1: Measured application rates

Section	Target application rate (kg emulsion/m^2)	Measured application rate (kg/m^2)	
		Emulsion	Residual binder (calculated based on 60% binder content)
1-1	0.07	0.12	0.07
1-2	0.14	0.25	0.15
1-3	0.21	0.38	0.23
2-1	0.14	0.24	0.14
2-2	0.21	0.36	0.22

3.2 Bond Strength

Results from measurement of shear and tensile bond strengths for emulsion types PMBE 1 and PMBE 2 (paving projects 1 and 2) are shown in figures 3 and 4 respectively. Since the shear and tensile tests were conducted under different loading rates and are based on different failure modes, it is not possible to directly compare the bond strength values. The shear bond strength values ranged between 1.35MPa and 1.44MPa for PMBE 1 and between 1.13MPa and 1.16MPa for PMBE 2. Shear bond strength from an earlier investigation where cationic bitumen emulsions were used ranged between 0.6 and 1.5MPa [5]. This indicates that the modified emulsions provided on average higher shear bond strength than the unmodified emulsions, but there is a large degree of uncertainty as different surface types are involved (some milled, some not milled and some new). The tensile bond strength values ranged between 1.29 and 1.52MPa for PMBE 1 and 0.88 and 0.92MPa for PMBE 2. The coefficient of variation ranged between 3% and 8% for shear bond strength test and between 2% and 7% for tensile bond strength test indicating good repeatability.

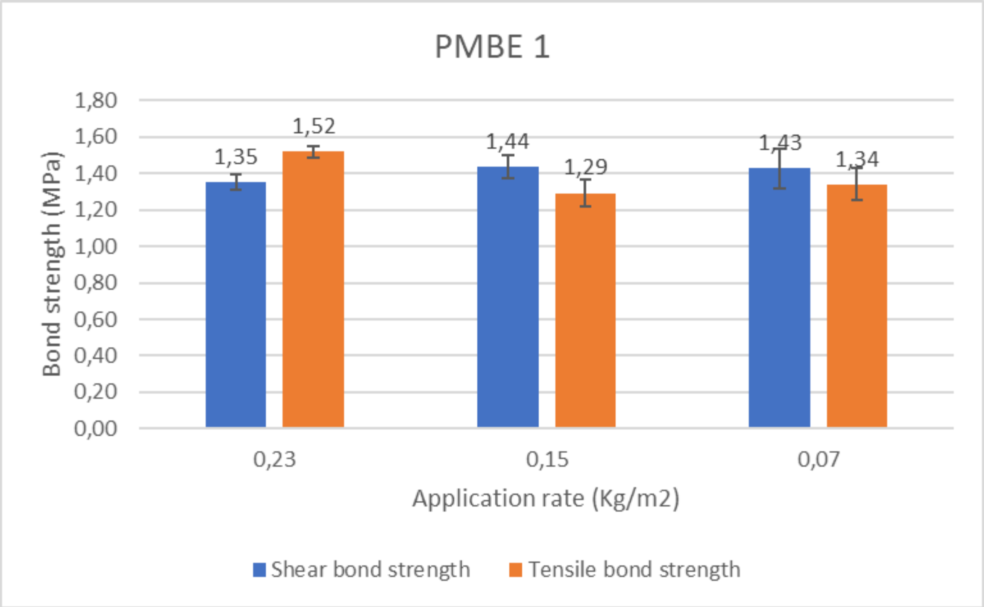

Figure 3 Shear and tensile bond strength for PMBE 1

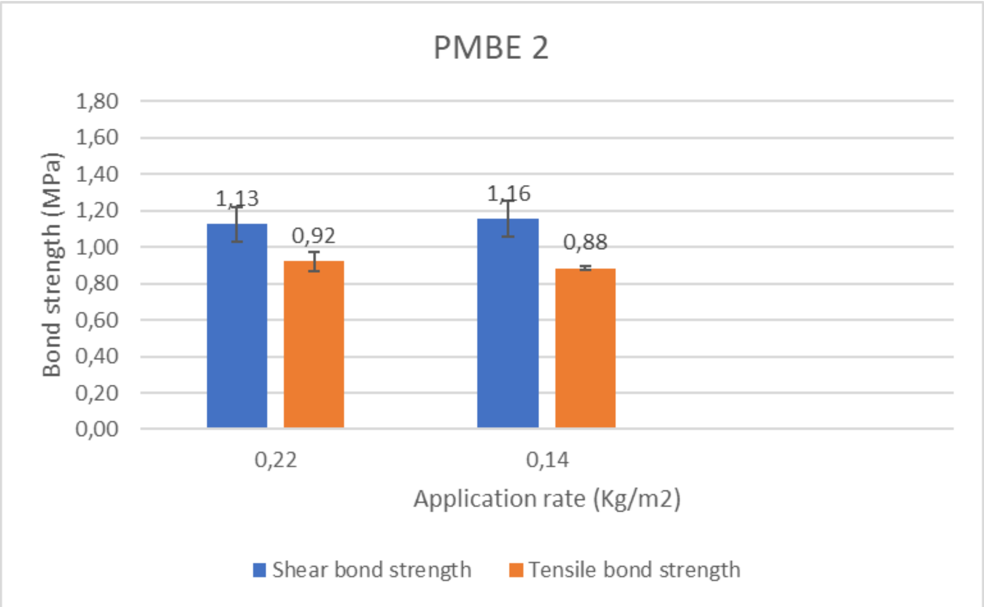

Figure 4: Shear and tensile bond strengths for PMBE 2

Figures 5 and 6 compare PMBE 1 and PMBE 2 based on shear bond strength and tensile bond strength respectively. As can be seen from the figures PMBE 1 had higher bond strength in both shear and tensile loading. PMBE 1is a latex-modified emulsion while PMBE 2 is an SBS-modified emulsion. This difference in bond strength might however be due to the condition of the underlaying layer. PMBE 2 was applied on a milled surface. It appears that the surface was not properly cleaned before paving as one can see some broken stone chips on the surface of the underlaying layer after the testing (see figure 7). This points to the importance of good workmanship and quality control during paving. It is often reported in the literature that milled surfaces give better bond strength than not milled surfaces. However, this might not be the case of if the surface is not thoroughly cleaned of broken/weakened stone particle after milling.

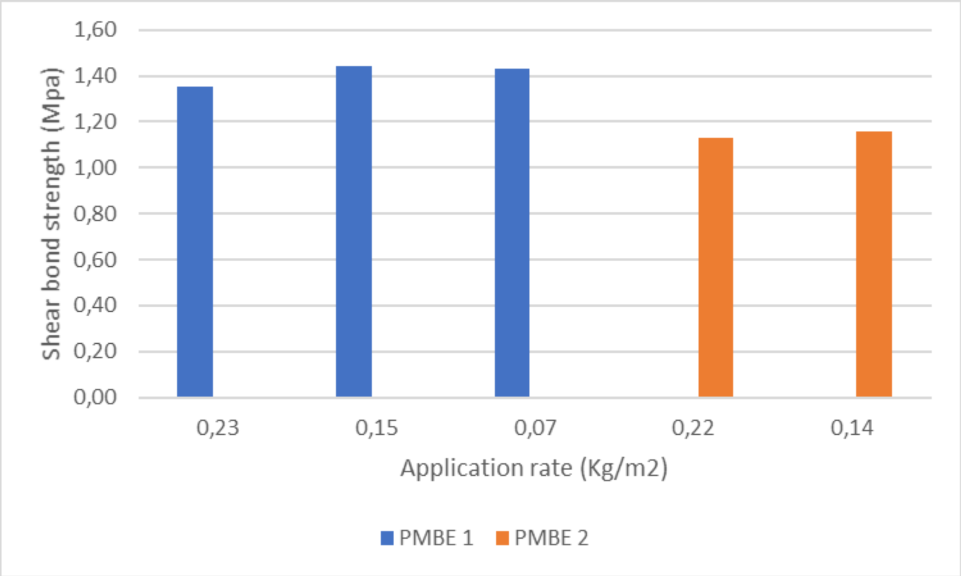

Figure 5: Comparison of PMBE 1 and PMBE 2 regarding shear bond strength

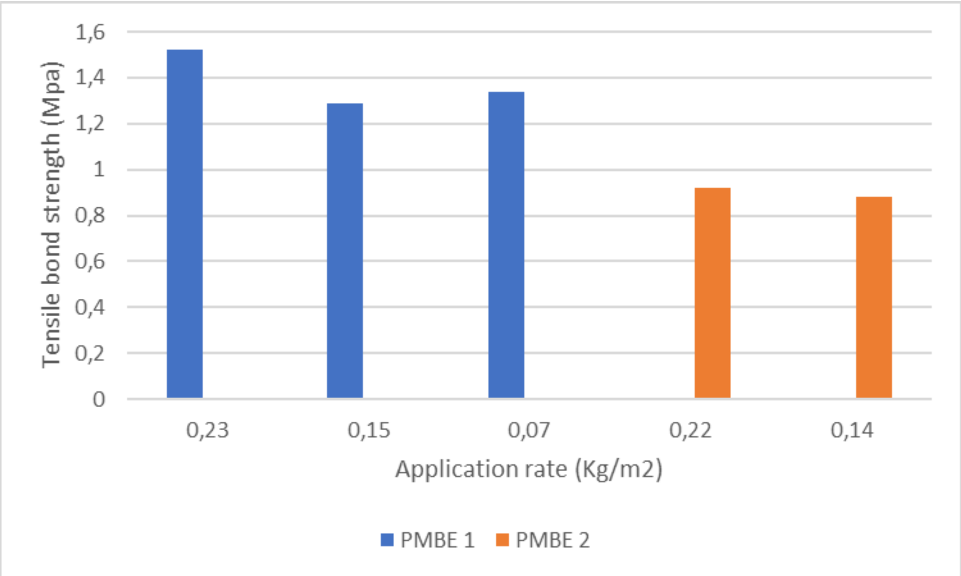

Figure 6: Comparison of PMBE 1 and PMBE 2 regarding tensile bond strength

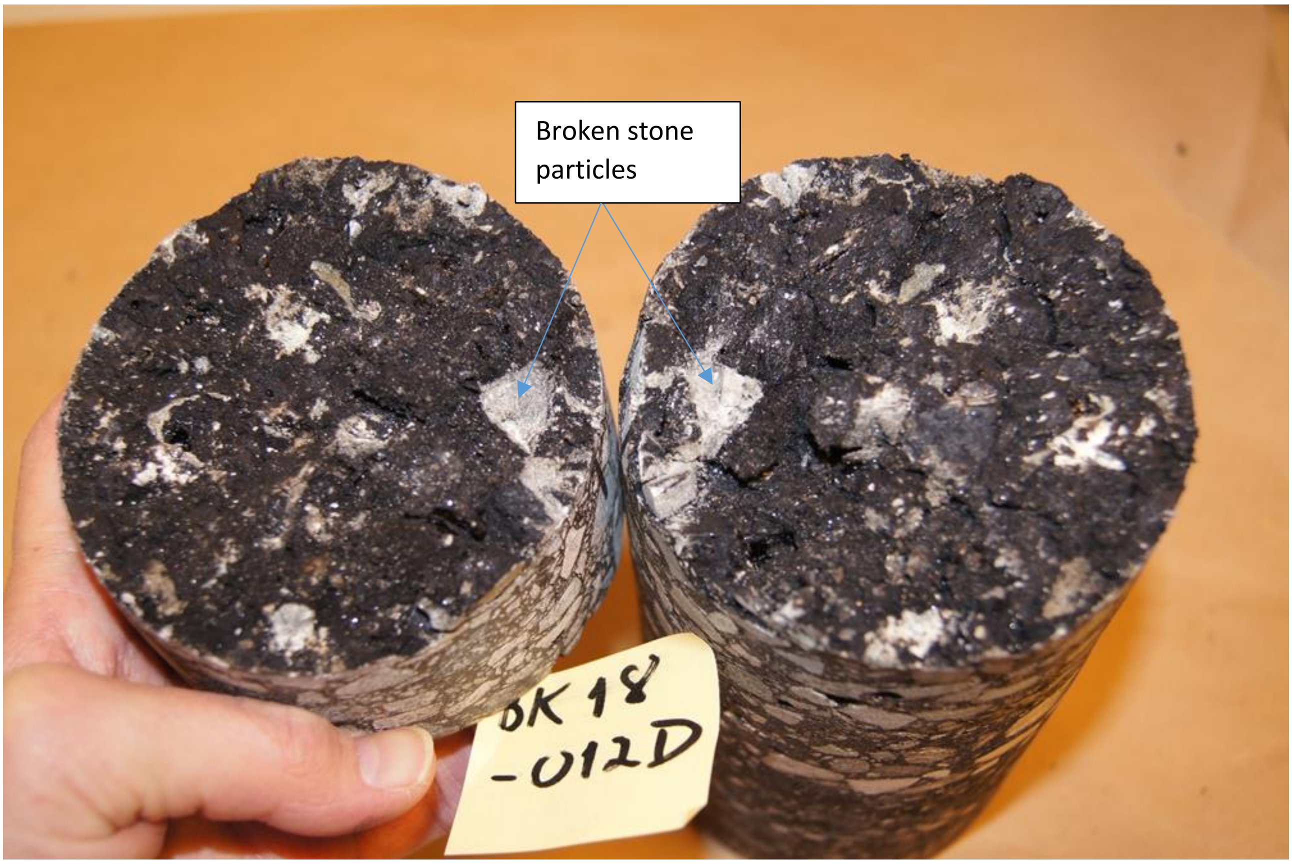

Figure 7: Broken stone particles on the surface after shear bond testing

3.3 Relationship between Application Rate and Bond strength

The main objective of this study is to have closer look at the correlation between application rate and interlayer bond strength in order to be able to determine optimum application rate. Figure 8 shows a plot of shear and tensile bond strength against application rate. Different functional forms were tried to fit the data, but no correlation could be found except a slight downward trend (weak correlation) of shear bond strength with increasing application rate. Shear bond strength data from previous investigation which was conducted in 2014[5] was added to data obtained in this study to see if larger data quantity can show some correlation between shear bond strength and application rate. These data are plotted in figure 9 for old asphalt surfaces, and in figure 10 for milled and new asphalt surfaces. The shear bond strength measurement in the previous investigation was conducted under the same condition as in the current study. However, the emulsions used in the previous study were unmodified cationic emulsions.

Figures 9 and 10 clearly show that there is no correlation between application rate and shear bond strength, with in ranges of application rate tested in these investigations, for all surface types considered. As shown in figure 8, the tensile bond strength also does not seem to be correlated to application rate. This shows the difficulty of determining optimum application rate based on bond strength testing. From road owner point of view, it is very important to set appropriate requirements based on measurable parameters. In this regard, the fact that one cannot see correlation between application rate and bond strength represents a significant challenge.

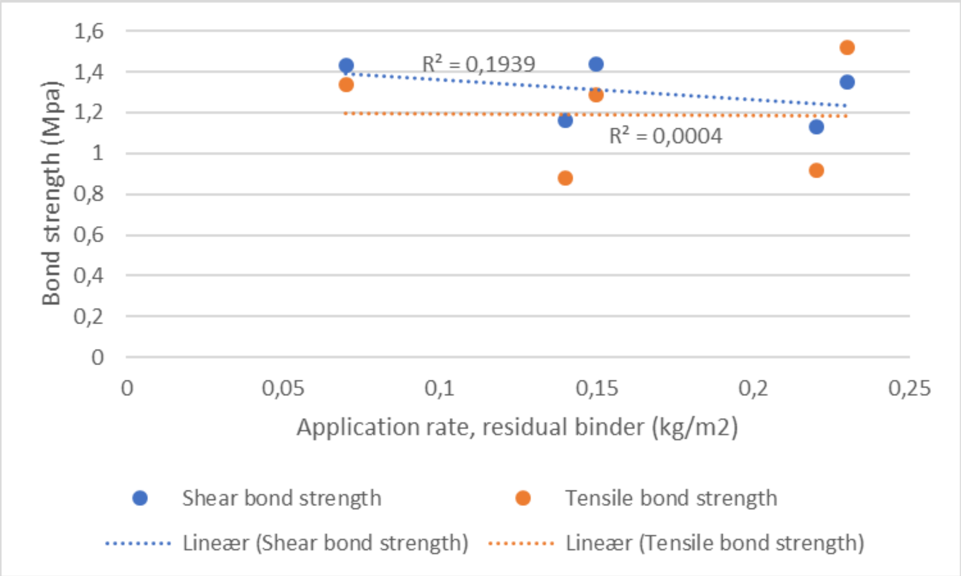

Figure 8: Correlation between application rate and bond strength

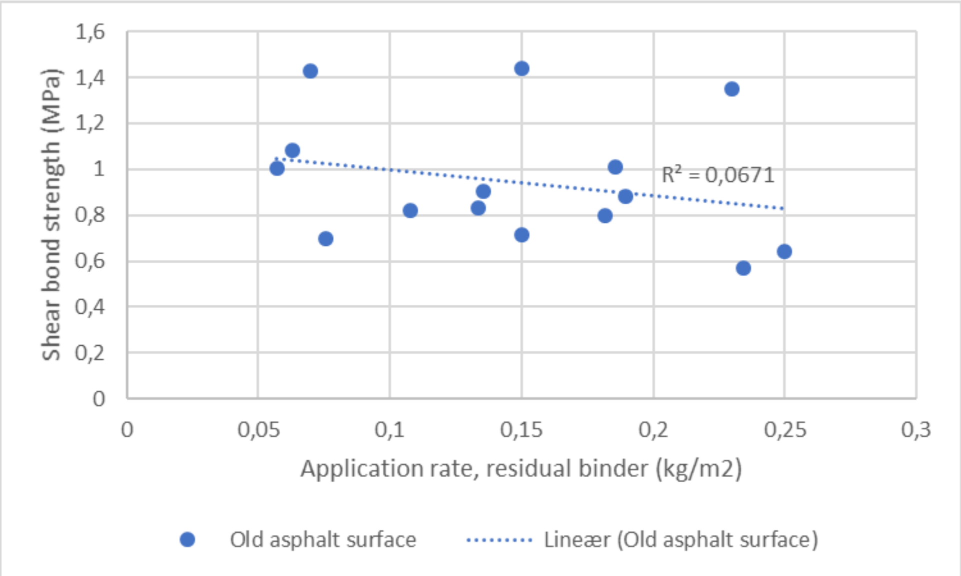

Figure 9: Correlation between shear bond strength and application rate on old asphalt surface

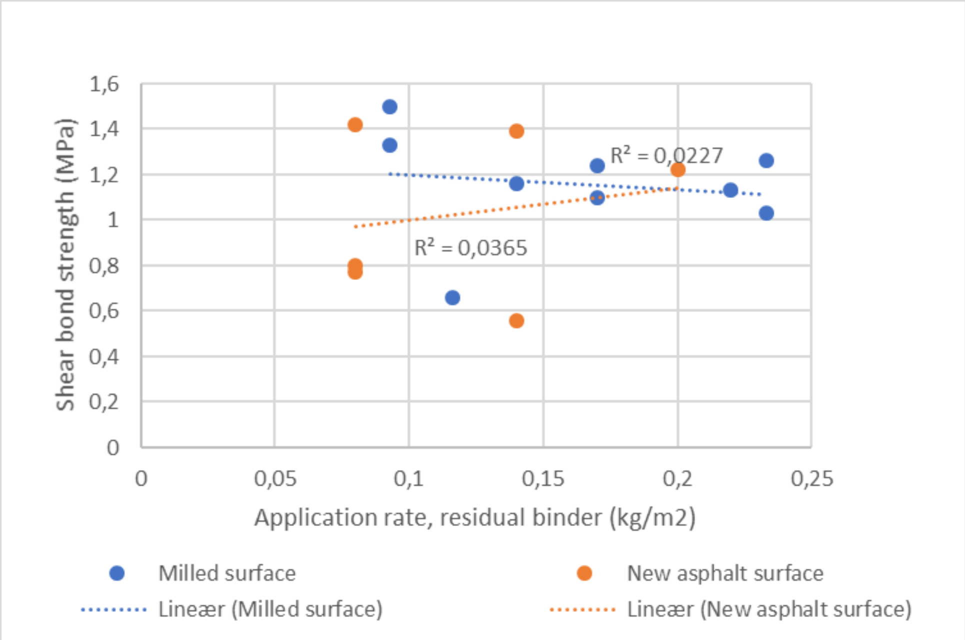

Figure 10: Correlation between application rate and shear bond strength for milled and new surfaces

4. CONCLUSIONS

An investigation of interlayer bond strength was conducted based on shear and tensile bond strength testing. The study was based on field and laboratory testing using two types of modified emulsions which were applied on five test sections. The purpose of the study was to evaluate the relationship between emulsion application rate and bond strength based on these two test methods in an attempt to find a way of determining an optimum application rate, which would form a basis for specification requirements. Data from similar investigation that was conducted in 2014 and in which shear bond strength testing was conducted under the same testing conditions were employed, in addition to data obtained in this study, to see if the shear bond strength is correlated to the application rate.

Data from tests conducted in the investigations reported in this paper show that there is no correlation between application rate and shear bond strength. There also seems to be no correlation between tensile bond strength and application rate but the data for this is so small that it is difficult to make firm conclusion. It appears that, on average, modified emulsions give higher shear bond strength than unmodified emulsions, but as different types of surfaces are involved in these studies and there are large variations in the data, it is not possible to make a firm conclusion.

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