Determination of Factors Affecting Shear Testing Performance of Asphalt Emulsion Tack Coats

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ABSTRACT

Tack coats are relatively thin applications of asphalt emulsion between the layers of a pavement structure. Their main role is to provide adhesion between the pavement lifts, to prevent slippage, and to confer adequate layer bonding for consolidating the whole pavement structure.

A wide variety of bitumen emulsions, spray rates and application techniques are specified worldwide for the construction of tack coats. There seems to be no consensus on how to design tack coat applications and there is not a lot of information about which parameters affect the performance of the finished product and to what degree.

The current paper describes a newly developed simple test method for measuring the performance of tack coats in shear. Using a carefully controlled specimen preparation protocol, the performance of a number of cationic and anionic emulsions prepared from asphalt cements of various stiffnesses were evaluated. An array of application rates and different substrate types were also tested to detect and quantify main tendencies, as well as optimum ranges for all the parameters in question. The scope of the study is to better predict the impact of all the described parameters on the field performance of asphalt emulsion tack coats.

RÉSUMÉ

Les couches d'accrochage sont de minces applications d'émulsion de bitume entre les couches de la structure de la chaussée. Leur rôle principal est de fournir une adhérence entre les couches de la chaussée pour prévenir le glissement et pour conférer un lien adéquat afin de consolider la structure entière de la chaussée.

Une grande variété d'émulsion de bitume, les taux et les techniques d'application sont spécifiés à travers le monde pour la construction des couches d'accrochage. Il semble n'y avoir aucun consensus sur la conception des applications des couches d'accrochage et il n'existe pas beaucoup d'information pour savoir quels paramètres affectent la performance du produit fini et à quel degré.

Le présent exposé décrit une nouvelle méthode simple d'essai pour mesurer la performance en cisaillement des couches d'accrochage. Avec un protocole de préparation bien contrôlée de l'échantillon, la performance d'un nombre d'émulsions cationiques et anioniques préparées avec des bitumes de rigidité différente ont été évaluées. Un ensemble de taux d'application et divers types de substrats ont aussi été testés pour détecter et quantifier les principales tendances aussi bien que les étendues de tous les paramètres en question. La portée de l'étude est de mieux prédire l'impact de tous les paramètres décrits sur la performance en chantier des couches d'accrochage d'émulsions de bitume.

1.0 INTRODUCTION

Flexible pavements are structures usually consisting of multiple layers of materials. In order to confer the maximum possible structural strength to such a pavement, it is necessary for the layers to be bonded together. Lack of adhesion between the various pavement lifts translates into higher deformation values for the entire structure, usually meaning higher rate of distress accumulation and shorter pavement life.

The adhesive material utilized between pavement layers is almost always an asphalt emulsion, known by the name of tack coat or bond coat. The tack coat is applied during pavement construction by spraying the emulsion to form a thin lift on top of the exposed pavement layer. Upon curing of the applied asphalt emulsion tack coat, the next pavement lift is constructed. With the heat and compaction of the newly applied hot mix asphalt, the cured tack coat layer bonds the two pavement lifts into one structure.

Provided the tack coat performs adequately, interfacial slippage between the bonded lifts will not occur. In an elastic or viscoelastic multi layered system this is an essential step for conferring strength to the structure as a whole.

2.0 REVIEW AND SCOPE OF WORK

2.1 Literature Review

Several very comprehensive studies on tack coat performance are available in literature. Considerable research efforts have gone into this chapter and it becomes evident again and again that tack coats are a small part of a pavement that plays a big role in ensuring the ultimate performance and durability of the entire structure.

A number of different laboratory tests were developed over the last 20-30 years aimed at measuring the effectiveness of tack coats. This is done mainly by measuring the bond strength and it can be performed in a number of different modes: in tensile, in shear and in torsion modes [1]. Some of the main devices and procedures that were developed for testing tack coat strength in shear are the ASTRA device developed in Italy [2]; the Superpave Shear Tester (SST) utilized by the University of Louisiana [3]; the Florida DOT bond strength device [4]; the Swiss LPDS tester [5] and the Tack Coat Shear Tester developed by Professor Al-Qadi [6].

The Quebec Ministry of Transportation developed a testing procedure and device named AMAC (Appareil de mesure d’adhesion des couches), capable of measuring laboratory specimens, as well as direct in-field measurements [7]. The loading type on the tack coat interface is in a tensile mode. A similar loading mode is applied by devices developed by Instrotek [8].

A National Cooperative Highway Research Program (NCHRP) study was initiated during 2005 to produce a comprehensive report regarding factors that are influencing the performance of tack coats. The main research agency for this project (NCHRP 9-40) is the Louisiana Transportation Research Center.

The Réunion Internationale des Laboratoires d’Essais et de Recherches sur les Matériaux et les Constructions (RILEM) has recently also initiated a study on tack coat performance under the Pavement Performance Prediction and Evaluation area. This study will evaluate a number of different methods of measuring the bond coat performance and their correlation with field performance.

2.2 Scope of Work

The current project was drafted after careful analysis of many of the existing research reports and publications. Extensive data exists on perfecting tests methods and testing devices. Compared to some highly sophisticated laboratory testing equipment, the device and procedure presented herein is inexpensive and easy to adapt and operate.

Our main focus, however, was not so much with the testing procedure but with the creation of a comprehensive test results matrix. Our project set-up was geared to capture relative performance of interfaces treated with carefully selected emulsions, having tightly controlled asphalt cements, application rates and nature of the pavement lifts creating the interface.

By quickly screening tack coating specifications around the world, it is readily obvious that almost all parameters specified are empirically selected. Application rates vary widely between provinces, states municipalities, with the usual selection criteria being positive experience. Similarly, a wide variety of asphalt emulsions are specified, for example slow sets (SS-1; CSS-1); diluted versions of slow sets (SS-1D, SCC-1D); rapid sets, cationic and anionic (RS-1; CRS-1). Some jurisdictions mandate soft asphalt cements (minimum residue penetration of 100 dmm); others specify much harder binders (ex. CRS-1H). A newer trend with some agencies is utilizing the so-called clean bond coats, usually emulsions utilizing very hard penetration asphalt cements.

There are a number of empirical and intuitive reasons and justifications for each and every one of these specifications. For example, the principal argument for utilizing slow set emulsions as tack coats is that the applied emulsion needs to be capable of making intimate contact with all the fine details of the surface before breaking. This way and this way only it will be capable of delivering good and effective adhesive strength. A rapid setting emulsion could break on contact with the fine dust or sand particles before it thoroughly wets and adheres to all the pores and surface details. One possible counter argument is that a slow set emulsion delays paving, as more time is needed for the tack coat to break and cure before traffic or the paving crew can safely drive on it.

On a different note, some experience suggests that a diluted emulsion is easier to spray into a uniform layer because of its lower viscosity. This enables better flow with better coverage of the microtexture and pores, also allows better spraying because the distributors have to spray higher volumes of liquid, and can deliver the material more uniformly. The counterargument lies with having to spray more water, which is undesired due to longer times required for curing and due to the increased cost of delivering a diluted product.

Such arguments can be made for or against a number of specification or field application parameters, with more or less research evidence available to support each and every one of them. The majority of research seems to agree that, both in laboratory and field environments, the absence of tack coat will severely compromise the performance of a pavement. Applying tack coat is no doubt beneficial and essential, even if we do not possess all the tools to this date for optimizing the application and therefore the performance of a tack coat.

As a result of the many opinions and beliefs about tack coats, our intention was to design the current study to try to cover the widest possible range of cases that are employed today or have the potential of being specified. The study includes rapid and slow setting emulsions, both anionic and cationic, a range of four different asphalt cements covering a penetration range from hard to soft; three application rates; and is looking at two different substrates, namely virgin hot mix and a RAP substrate.

3.0 EXPERIMENTAL WORK

3.1 Material Selection

The experimental work was initiated by producing a total of 16 different asphalt emulsion samples, using carefully controlled compositions. The emulsion sample matrix was designed to cover as wide as possible ranges of asphalt cement hardness and setting times. The group of emulsions tested can be classified in four groups: anionic slow setting, anionic rapid setting, cationic slow setting and cationic rapid setting. The emulsifier chemistries selected for each of these groups is a commercially available emulsifying system and all the process parameters were held in line with a typical formulation for each emulsion type.

The asphalt cement was the second parameter to be varied inside each emulsion groups. Four different asphalt cements were selected, to cover a broad penetration range. Based on the Penetration (Pen), the four asphalts used would grade as a 20/30 Pen, 60/70 Pen, 120/150 Pen and a 150/200 Pen. All four asphalt cements were originating from Western Canadian crude sources.

Since each emulsion type was produced using each of the four asphalts, the nomenclature selected for the emulsions is as follows: each emulsion produced using the 20/30 Pen asphalt has the suffix “HH”; the emulsions produced using the 60/70 Pen asphalt carry the suffix “H” and the emulsions produced with the 150/200 Pen asphalt carry the suffix “S”. The emulsions containing 120/150 asphalt cement have no suffix attached to their label. Table 1 lists the 16 emulsion samples and their main characteristics.

Table 1. Tack Coat Emulsion Samples and their Characteristics

Emulsion	Asphalt Cement	Residue, %	SF Viscosity, 25°C, SFS	Particle Charge
RS-1HH	20/30 Pen	62.2	23.5	Negative
RS-1H	60/70 Pen	61.8	28.7	Negative
RS-1	120/150 Pen	62.3	27.0	Negative
RS-1S	150/200 Pen	62.2	27.8	Negative
SS-1HH	20/30 Pen	61.8	26.8	Negative
SS-1H	60/70 Pen	62.3	30.3	Negative
SS-1	120/150 Pen	61.5	31.2	Negative
SS-1S	150/200 Pen	61.6	28.8	Negative
CRS-1HH	20/30 Pen	65.1	30.1	Positive
CRS-1H	60/70 Pen	65.3	38.2	Positive
CRS-1	120/150 Pen	64.8	34.1	Positive
CRS-1S	150/200 Pen	65.3	36.5	Positive
CSS-1HH	20/30 Pen	62.1	28.1	Positive
CSS-1H	60/70 Pen	62.5	27.8	Positive
CSS-1	120/150 Pen	62.8	25.6	Positive
CSS-1S	150/200 Pen	62.8	27.0	Positive

The parameters of the emulsions described above were held as close as possible so that any influence of any secondary factors on the shearing of the tack coat specimens is minimized.

The hot mix used for the experiment was a Heavy Duty Binder Course (HDBC) mix, sampled from production from Miller Paving's asphalt plant in Richmond Hill, Ontario. The hot mix design data is presented in Table 2.

Table 2. Hot Mix Composition and Properties

Job Mix Formula Blend	**Materials**	
	Source	**Percentages (%)**
19mm Clear Stone	Carden Quarry	25.5
9.5mmStone	Carden Quarry	23.5
Manufactured Sand	Carden Quarry	51.1
PG 64-28	McAsphalt	4.70
Physical Properties		
Parameter	**Selected**	**Specification**
Stability @ 60 °C (N)	14,250	12,000 min
Flow Index (0.25mm)	11.5	8.0 min
Air Voids (%)	4.5	3.5 – 4.5%
VMA (%)	14.3	13.0% min
BRD (kg/m3)	2.390	-
MRD (kg/m3)	2.502	

Note: VMA is Voids in the Mineral Aggregate
BRD is Bulk Relative Density and MRD is Maximum Relative Density

The Reclaimed Asphalt Pavement (RAP) used for the current experiments originates from Miller Paving from the Markham, Ontario yard. The RAP was graded and the Asphalt Cement (AC) was extracted, recovered and tested. The AC content was 3.7 percent and the recovered penetration was 20 dmm.

3.2 Experiment Design

3.2.1 Preparation of Specimens

The specimens were prepared for the tack coat shear testing by using a Pine gyratory compactor and four inch gyratory moulds. The first lift of asphalt, or substrate, was gyrated into the mould at the normal compaction temperature for the mix (approximately 1000 grams/specimen). The mix was subjected to 100 gyrations for this stage.

After compaction of the first stage was completed, the briquettes were left into the mould to cool to room temperature. Once room temperature was achieved, the mould containing the substrate was loaded on a digital balance and the desired level of tack coat was applied by means of a paint brush. Care was exercised for applying the tack coat emulsion only to the exposed face of the asphalt and not to the side walls of the mould. The moulds were then left under a fan for the tack coat to cure. This usually took less than 2 hours, with some emulsions requiring much less time.

After the tack coat cured, the second lift of asphalt was loaded in the mould, on top of the existing tack coated surface and was compacted for 50 gyrations. This lower number was selected to avoid over-compacting the interface and make it more difficult for the testing to differentiate between tack coats. Because the mould and the substrate were cold during the second compaction, and because the top lift received a reduced number of gyrations, the top lift has noticeable lower density than the bottom (Figure

1). However, this was considered not to be an impediment for being able to measure the effectiveness of the tack coat between the two mixes.

Figure 1. Specimen Texture

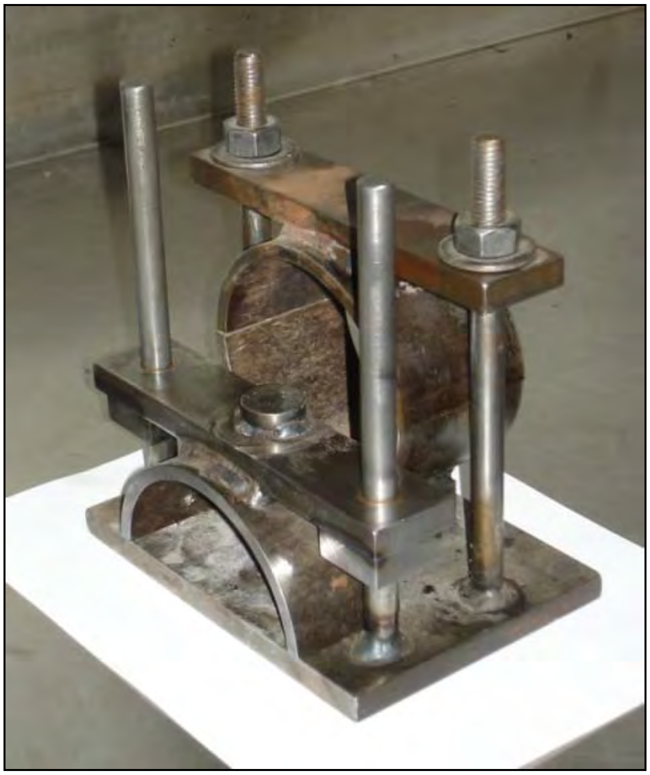

Figure 2. Shear Testing Device

The procedure for specimen preparation was selected so that it replicated, as close as possible, field paving conditions. During planning of the experimental work, a number of alternate methods were considered for preparing the specimens. These included gluing two briquettes using the tack coating emulsion. While this procedure had the potential to be more precise and possibly generate tighter test results, it was felt that compacting the hot mix on top of the existing tack coated substrate is the closest we can ever replicate field conditions in a mould.

Two sets of test samples were prepared. The first used the same hot mix for both the substrate and top lift. Each emulsion of the 16 described was applied in three application rates: 0.05, 0.1, and 0.15 kg/m^2 of residual asphalt. This translates into approximate emulsion application rates of 0.075, 0.15, and 0.225 l/m^2, respectively, with small variations due to the different emulsion residues. For each data point a set of duplicate specimens were prepared. The tack coat application rates were selected to cover the rates that correspond to most of the provincial and municipal specifications in Canada. Some other jurisdictions around the world (ex. Europe) have significantly higher specified application rates for tack coats [9].

The second set of samples was identical to the first, the only difference being that the substrate did not consist of HDBC hot mix, but of compacted RAP. This was decided as the best available option for replicating an old, aged hot mix surface. This set therefore attempted to replicate a hot mix overlay of an existing older roadway. As with the virgin hot-mix, duplicate specimens were prepared for each point.

For both sets of samples, specimens without tack coat were prepared as benchmarks.

3.2.2 Testing Equipment and Procedure

For testing the specimens in shear, a simple device was developed. The device is in many ways very similar to the Florida DOT device. It consists of a modified Marshall Stability mould, designed to clamp and fasten one end of the briquette using a set of nuts. The other part remains suspended and is covered by a semi-circular shear sleeve, designed to fit around the exterior of the specimen. This sleeve rslides on a set of guide rods that only allow it to move in a vertical plane, almost frictionless. The shear is applied at the top of the sleeve, immediately adjacent to the interface. A picture of the shearing device is shown in Figure 2.

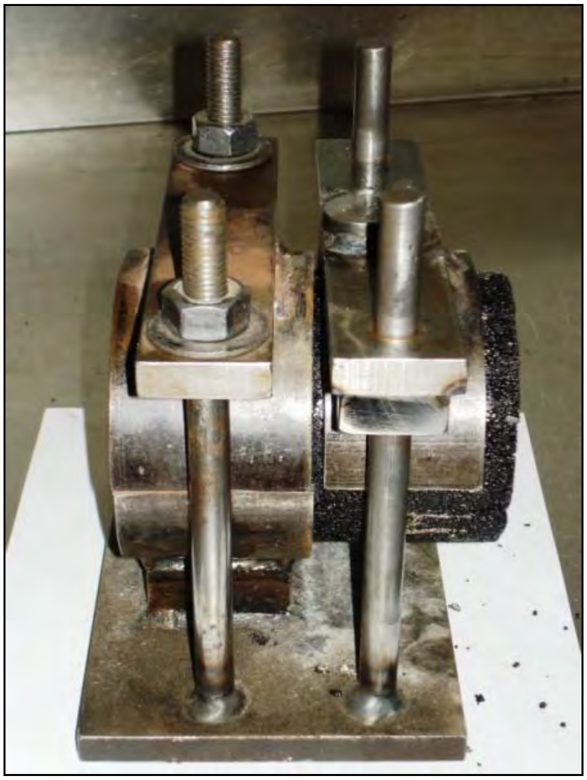

Figure 3. Mounted Specimen and Shear Plane

Figure 4. Assembly Ready for Testing

The briquette is fastened into one side of the shearing device, positioned so that the interface aligns perfectly between the locking mould side and the shear sleeve (Figure 3.) The distance between the clamping device and the shearing sleeve is about 5 millimetres. The entire device gets loaded into a Pine Marshall Stability machine and the shearing is applied at a displacement rate of 50.8 millimetres/minute (Figure 4). The machine displays the load in pounds versus the displacement of the two specimen parts. From this, the peak shear stress can be calculated, which represents the shear strength of the bonded interface. The shear testing device and the test method described here is suitable for testing both laboratory specimens and field cores of 4 inch diameter.

Exiting research [2] shows that the peak shear stress of a multilayer pavement interface can be expressed as a sum of the contribution of different shear stresses as shown in Equation 1.

$$\tau_{peak} = \tau_{res} + \tau_{ic} + \tau_{res} + \tau_{a} \quad (1)$$

Where

τ_{res} = residual friction
τ_{ic} = inner cohesive friction
τ_{d} = dilatancy effects
τ_{a} = adhesion friction given by the tack coat; zero in the absence of tack coat

For our testing method the peak shear stress can be calculated by dividing the peak load recorded during the shear test (F) to the area of the interface (S) as shown in Equation 2.

$$\tau_{peak} = F/S \quad (2)$$

By also testing specimens without any tack coat, we can this way estimate the contribution of the τ_{a} component, when all other conditions are identical. It is known that both τ_{res} and τ_{ic} are dependent on the normal force applied on an interface during shear testing, which is zero in our testing environment. Even though the presence of tack coat at different application rates can affect the internal cohesion of the materials, we believe this effect to be secondary to the adhesive role.

4.0 RESULTS AND DISCUSSION

4.1 Virgin Mix Substrate Results

The testing of all the specimens produced using virgin hot mix as a substrate was done as described in Section 3. For each specimen, the maximum load was recorded and subsequently the interface shear strength was calculated. All tests were done at room temperature; no temperature variable was studied or taken into account. All presented values are average values of two measurements. A summary of the strengths of all the specimens are presented in Table 3.

For a better visualisation of the test results, Figures 5 through 8 display shows the bar charts, grouped by emulsion classes, of the interface shear strength as a function of the tack coat residue application rate, in kg/m^2.

The CRS-1HH tack coat data could not be generated, because the emulsion was too unstable and broke before the specimens could be produced.

4.2 RAP Substrate Results

Similarly with the virgin hot mix substrate, the data presented above is a summary of the results obtained when using RAP as a substrate. The interface shear strength values are presented in Table 4 and the Figures 9 through 12 display the data by emulsion groups and applications rates.

Table 3. Interface Shear Strength for Tack Coats on a Virgin Hot Mix Substrate

Application Rate, kg/m^2	RS-1HH, kPa	RS-1H, kPa	RS-1, kPa	RS-1S, kPa
0	759			
0.05	1395	1587	1456	1465
0.01	1679	1606	1523	1487
0.15	1465	1530	1289	1247
Application Rate, kg/m^2	**SS-1HH, kPa**	**SS-1H, kPa**	**SS-1, kPa**	**SS-1S, kPa**
0	759			
0.05	1417	1657	1572	1544
0.01	637	1509	1679	1757
0.15	997	969	1629	1326
Application Rate, kg/m^2	**CRS-1HH, kPa**	**CRS-1H, kPa**	**CRS-1, kPa**	**CRS-1S, kPa**
0	759			
0.05	N/A	1635	1626	1397
0.01	N/A	1431	1686	1487
0.15	N/A	1519	1360	1417
Application Rate, kg/m^2	**CSS-1HH, kPa**	**CSS-1H, kPa**	**CSS-1, kPa**	**CSS-1S, kPa**
0	759			
0.05	1629	1555	1660	1116
0.01	1680	1589	1283	1601
0.15	1530	1516	1374	1398

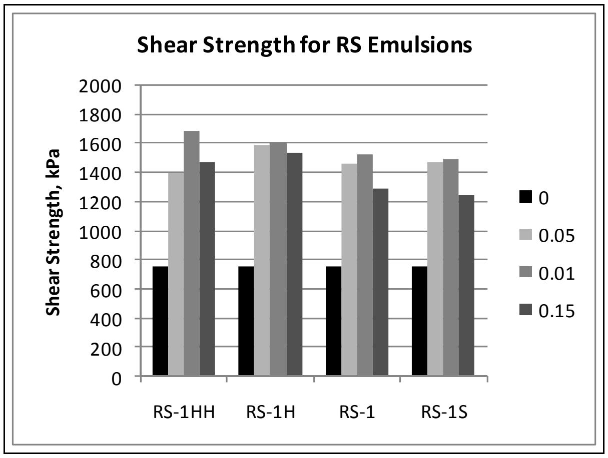

Figure 5. RS Tack Coats on Virgin Hot Mix

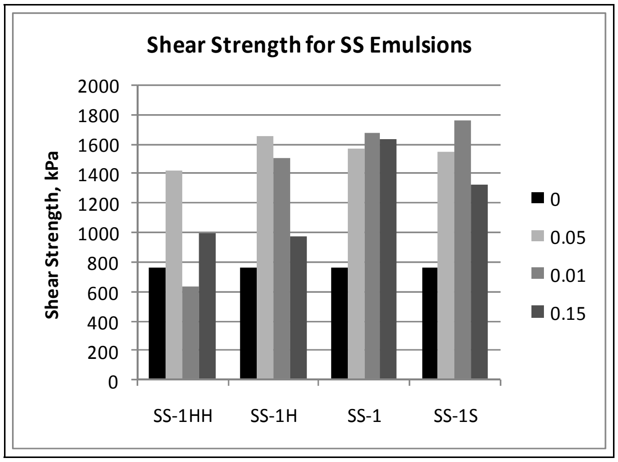

Figure 6. SS Tack Coats on Virgin Hot Mix

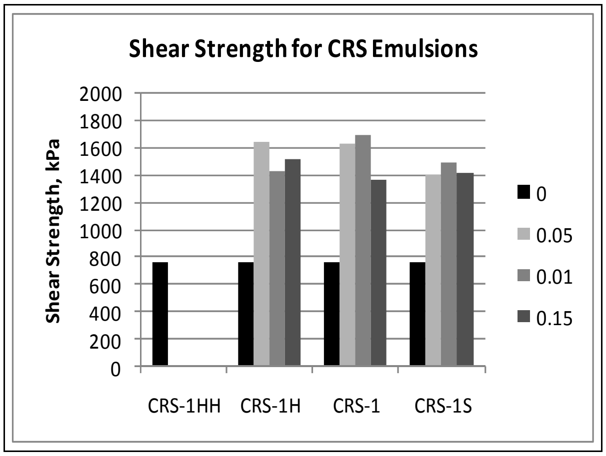

Figure 7. CRS Tack Coats on Virgin Hot Mix

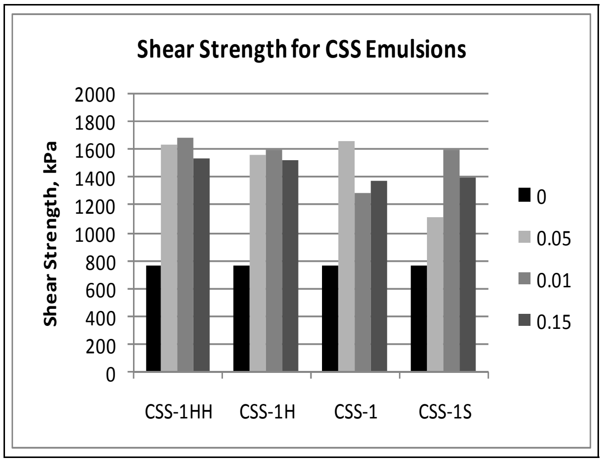

Figure 8. CSS Tack Coats on Virgin Hot Mix

Table 4. Interface Shear Strength for Tack Coats on a RAP Substrate

Application Rate, kg/m^2	RS-1HH, kPa	RS-1H, kPa	RS-1, kPa	RS-1S, kPa
0	793			
0.05	1456	1445	926	1096
0.01	N/A	816	992	864
0.15	N/A	1009	907	1261
Application Rate, kg/m^2	**SS-1HH, kPa**	**SS-1H, kPa**	**SS-1, kPa**	**SS-1S, kPa**
0	793			
0.05	1643	1521	1725	1601
0.01	1162	926	1194	1068
0.15	934	992	949	856
Application Rate, kg/m^2	**CRS-1HH, kPa**	**CRS-1H, kPa**	**CRS-1, kPa**	**CRS-1S, kPa**
0	759			
0.05	N/A	1502	1534	1434
0.01	N/A	890	1062	992
0.15	N/A	992	1014	827
Application Rate, kg/m^2	**CSS-1HH, kPa**	**CSS-1H, kPa**	**CSS-1, kPa**	**CSS-1S, kPa**
0	759			
0.05	2029	1468	1439	1638
0.01	1026	1771	1082	1034
0.15	1024	N/A	N/A	N/A

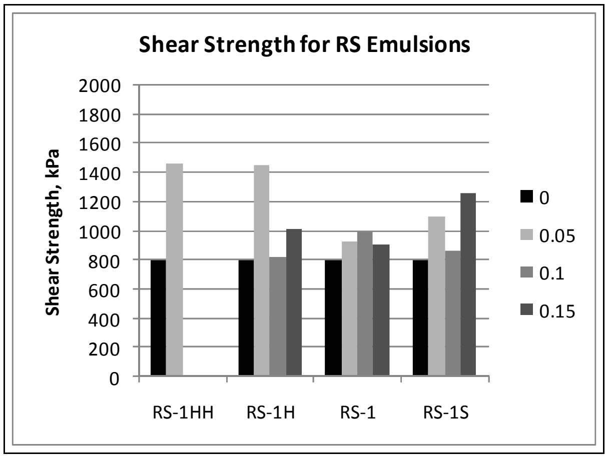

Figure 9. RS Tack Coats on RAP

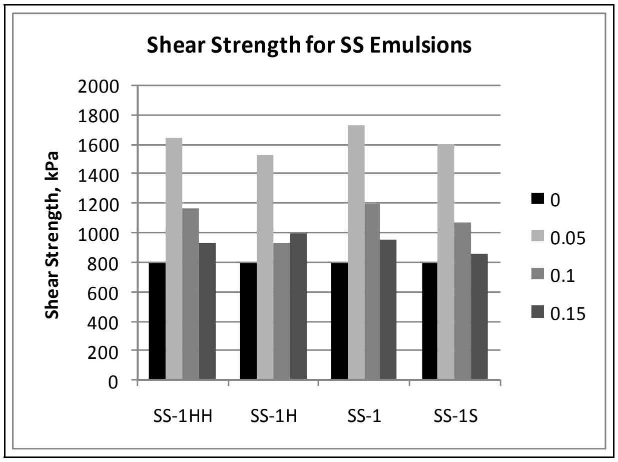

Figure 10. SS Tack Coats on RAP

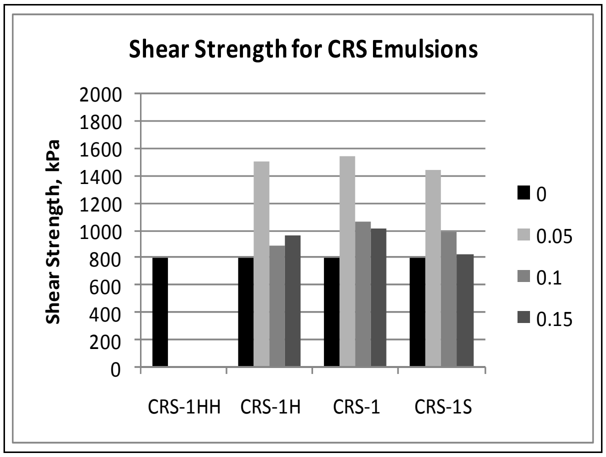

Figure 11. CRS Tack Coats on RAP

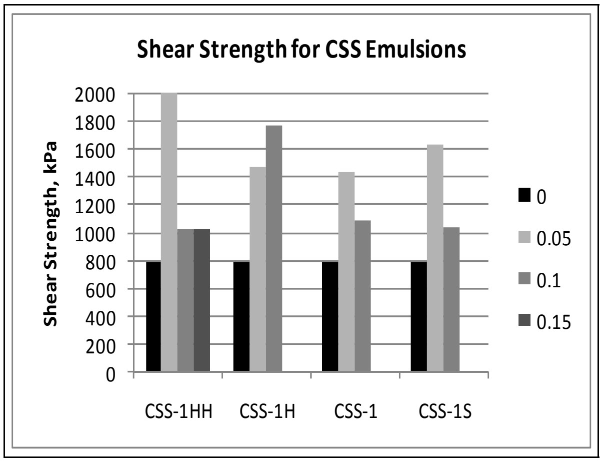

Figure 12. CSS Tack Coats on RAP

The CRS-1HH and subsequently also the RS-1HH emulsions proved to be too unstable to be able to complete all the planned test results. Furthermore, the final results using the CSS emulsions at 0.15 kg/m^2 residue application rate could not be completed in time because a breakdown in our gyratory compaction device.

4.3 Discussion of the Results

In visually analyzing the specimens after testing, it can be seen that the failure clearly happens in the tack layer without tearing, scratching or destroying the surface of the mix in any way. This is an excellent fact, as it supports the belief that the test set-up is essentially correct and that the shear stresses measured are in fact measuring the shear strength of the bond itself.

It is immediately visible from analyzing the presented results that the interface bond strengths are generally higher when tack coat is used. The role of tack coats in increasing structural strength was never in question and it has been proven in the lab and in the field. However, some published data trying to measure bond strength by different shear tests have occasionally observed that non-tacked specimens can display higher bond strengths in a laboratory environment than specimens that were using tack coats [2]. This was attributed to possibly too high tack application rates selected for the respective testing conditions. This behaviour was not observed in our case, the worst performing tacked specimens displayed bond strengths that are roughly similar or slightly higher than the benchmark non-tacked samples.

It is difficult to detect a clear trend that is encompassing all emulsion types and all asphalts that were used to prepare the emulsions. The answer isn't as easy as seeing a clear trend that correlates with the setting characteristics of the emulsion of with the hardness of the asphalt cements. The results are likely affected by a much larger number of factors. It the following paragraphs we will try to interpret some of the measured results and propose some reasons capable to elucidate some observed behaviours.

In analyzing the virgin hot mix substrate data, we can see that with the exception of a few isolated samples that are likely outliers, the interface bond strengths of the samples using tack coats are about double as compared to the non-tacked specimens. Furthermore, if we look closely at specific emulsion types, some trends become apparent. For example, for RS emulsions on hot mix substrate, harder constituent binders give slightly better results that softer ones, with the 0.1kg/m^2 residual application rate showing the highest results. However, the differences in shear strengths are pretty small and they are no longer evident if we look at the SS emulsions, for example. The slow sets tend to favour the softer binders slightly, again with the 0.1kg/m^2 residual application rate generally proving to be the best. It can be stated that no clear trend can be detected that the stiffness of the asphalt cement has any significant impact on the tack coat performance.

One general observation that becomes evident is that, overall, the highest application rate does not necessarily translate into higher bond strengths. This is in agreement with a recently published study [3] where it was observed that higher tack coat applications almost always resulted in higher strengths in the field, but showed the opposite behaviour in the laboratory. In the mentioned study, the tests were performed on laboratory-prepared and field-collected samples and the shear tests were done at much lower loading rates. Shear test results on tack coated samples are extremely sensitive to sample preparation and testing conditions. Higher shear testing speeds will produce higher bond strengths. Also, laboratory samples usually show significantly higher strengths compared to field samples. It would be interesting to pursue a field trial with the same application rates as our current study, to verify if the optimum application rates in the field disagree with the laboratory results. Differences between laboratory and field in compaction methods, mix density, surface cleanliness and other factors might easily explain the different observations.

Continuing our data analysis, the observation that more might not necessarily be better is even more evident when analyzing the RAP substrate results. Here, the lowest application rates often produced better results, with the higher rates showing decreasing bond strengths. In trying to explain the behaviour, we observed that the compacted RAP briquettes used as a substrate had much smoother surfaces than the virgin hot mix. This could be a factor explaining the decreasing strengths with higher emulsion application rates. Application of 0.05 kg/m^2 of residual asphalt will translate into a 50-micron thick film of asphalt if applied on a perfectly smooth surface. The higher the voids and the surface roughness, the more the film thickness on the effective contact area will decrease, as some material will be lost in voids and macrotexture indentations and will not contribute as an adhesive for the interface. It is possible that higher application rates of tack delivered on the smoother RAP briquettes created an asphalt film sufficiently thick to create a slippage plane at the interface and therefore weaken the bond, when compared to the specimens with less tack coat. However, even the weaker “high tack” specimens still exhibit better strengths than the non-tacked samples. They are only weaker when compared to specimens whose tack application rate might be closer to the optimum.

The difference in surface smoothness between the two substrates could also explain the generally higher bond strengths observed with the virgin hot mix samples. It was previously shown [3] that interface shear strengths are generally higher for materials with higher surface roughness. However, our data shows that the virgin hot mix substrate (rougher surface) has higher shear strength values when looked at across the entire range of the application rates. The RAP substrate samples show similar strength values as the virgin hot mix but only around the optimum application rate for the tack coat. In other words, rougher textures might be capable of tolerating a wider range of tack application rates while maintaining good performance. Smoother surfaces might show a narrower optimum application rate and the performance might drop faster when the tack coat dosages get further away from this range.

The shear strength data presented will continued to be analyzed in the future, as more data will be generated and the influence of more factors will be added to the current study. We intend to assess other parameters, such as the presence of polymer in the tack coat emulsions, the influence of temperature on the interface bond strength and the tack coat behaviour on different substrate surfaces, such as milled hot mix and Portland Cement Concrete. Naturally, the ultimate answer about the relevance of the current laboratory study is obtaining field data and examining its correlation with our current observations and conclusions.

5.0 CONCLUSIONS AND SUMMARY

The objective of the current study was to investigate the interfacial shear strengths of tack coated multi layered pavement samples under carefully controlled conditions. A number of cationic and anionic asphalt emulsions were prepared, having residual asphalt cements of different stiffness and having setting ranges from rapid to slow. The emulsions were applied as tack coat on top of an existing asphalt surface and after curing, new hot mix was compacted on top using the gyratory compactor.

A simple shear testing device was developed, capable of testing the interfacial shear strength of 4-inch diameter laboratory specimens and field cores. The shear testing is done by using the Marshall Stability machine. The testing procedure records the load versus displacement and the interfacial shear strength is then calculated from the peak load.

Testing of tack coated samples was done using two different substrates representing a new asphalt surface and an old, aged pavement surface. Three different emulsion application rates were used, translating into residue application rates of 0.05; 0.1 and 0.15 kg/m^2. Specimens without tack coats were tested as benchmarks. Interfacial shear strength data was collected for each of the emulsion and of the substrates. Here are some of the observations.

There is a significant increase in interfacial shear strengths for all the tack coated samples when compared to the non tacked specimens. The bond strength increase can be as high as double or even higher, in most of the samples.

Little influence of the hardness of the residual asphalt cement was observed on the bond strength. There seems also to be little influence of the emulsion type, cationic or anionic, slow set or rapid set. The parameters that show to impact the interface behaviour more are the tack coat application rate and the nature of the substrate.

The rougher surface texture of the virgin hot mix substrate is less sensitive to application rates, showing good interfacial strengths across a wider tack application interval. The RAP substrate provided a smoother surface texture and seems to be more sensitive to application rates. Lower tack dosages confer high interfacial strengths, but too much tack coat creates a slippage plane and starts weakening the bond. However, all tack coat interfaces showed higher strengths than the non-tacked samples. Any tack is still better than no tack and you cannot lower the interface shear strength by selecting a wrong emulsion type or a wrong residual asphalt type. The experimental data prove that the contribution of the adhesion friction τ_a to the value of the peak shear stress τ_{peak} is significant and should not be neglected.

Future research in this area should include more surface types (ex. PCC, milled HMA), as well as study the influence of factors such as temperature and polymer modification on the tack coat performance. Ultimately field study and field measurements are needed to validate the existing conclusions based on laboratory data.

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