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Physical mechanical performance of asphaltic emulsions in road oil for flexible pavements

J G Bastidas-Martínez¹, J C Ruge¹, I J Paba¹, F Vasquez¹, and J P Rojas Suárez²

¹ Facultad de Ingeniería, Universidad Católica de Colombia, Bogotá, Colombia

² Facultad de Ingeniería, Universidad Francisco de Paula Santander, San José de Cúcuta, Colombia

E-mail: jgbastidas@ucatolica.edu.co

Abstract. The present study evaluated experimentally, the impact of the application rate, in terms physical and adherence, of four types of emulsions used as road oiling in two asphaltic layers for flexible pavements. Asphaltic layers are composed by an asphaltic base and a hot mix asphalt surface layer. To evaluate the adherence and physical properties, a shearing test was carried out. Four rapid set cationic emulsions were used, by means of three application rates of 0.33 l/m², 0.50 l/m², and 0.65 l/m² (recommended values in Colombian road construction practices). The results demonstrate that an emulsion application rate of 0.50 l/m² guarantees better adherence in the structural package. Also, that greater resistance against the sliding of the surfaces of the specimens in the shearing test, depends on the residual content of the asphaltic emulsion.

1. Introduction

The surface layer of a pavement has several structural and functional functions; structurally, this layer should be able to dissipate normal and shear stresses induced primarily by the traffic loads and functionally, it should assure the comfort, safety and durability of the pavement. In order to guarantee the structural and functional aspects of the pavement, the compatibility between the constituent layers must be guaranteed by means of its bond. To ensure a strong adhesive bond of the different layers of a pavement, a tack coat or a prime coat should be applied between hot mixture asphalt (HMA) layers or HMA and granular layers respectively [1]. In some cases, it is necessary to use granular layers stabilized with hydraulic additives (*i.e.* lime, cement or asphalt materials) in order to guarantee a proper stiffness of the base layers. For this type of layers, a coat of rapid set asphalt emulsion should be applied over the stabilized base to ensure a seal and prevent the evaporation of the water used in the compaction of the material. Further details of the application of the different types of coats can be consulted in the technical specifications for the construction of roads of the “Instituto Nacional de Vías (INVIAS)”, Colombia, or according to the “Instituto de Desarrollo Urbano (IDU)”, Colombia [2,3].

With the aim of improve the flexible pavements construction process, several studies have been focused on understanding the effect of an improper tack or prime coat application between pavement layers [4]; statistically conclude that half-moon cracks on the surface layer, are caused mainly by the lack of adherence between the surface layer and the granular base; which can be due to the presence of impurities and lack of a prime coat between the layers [5]. Furthermore, [6] prove that even though rough texture of the aggregates contributes to a better adhesion between the base and surface layers, the



presence of wet aggregates generates a significant decrement of the adherence of the coat; also that cut-backs asphalts coats generates a weaker adherence in reference to asphalt emulsion ones [6].

To determine the adhesive properties of different emulsion tack coats and different application procedures, the superpave shear tester (SST), a direct cut device, is conducted in this research as it permits to quantify the shear resistance of two bonded layers interface. In 1997, an asphalt emulsion tack coat, modified with recycled tire rubber, is evaluated in terms of shear resistance. It is found that under low temperatures this material provides better adherence than conventional emulsions [7]. In the same way, this test is used by [8] to evaluate the impact of the emulsion application rate over the adhesion strength of two bonded layers. They evaluate five different application rates (*i.e.* 0.00 L/m², 0.02 L/m², 0.05 L/m², 0.10 L/m² and 0.20 L/m²) and results show that under the SST, the highest shear resistance of the interface between layers was obtained when the emulsion is applied at a rate of 0.02 L/m². A similar result is found by West *et al.*, 2005, [9], who evaluated three different application rates (0.02 L/m², 0.05 L/m² and 0.08 L/m²), to generate a proper bond with two different HMA mixtures (*i.e.* with fine and coarse granulometries). They find that low application rates present better adhesive properties for fine mixtures, while for thick mixtures the application rate does not impact significantly the performance of the interface in terms of shear resistance. All these findings agree in the importance of a proper tack coat application, as a poor execution or an inadequate application rate of the asphaltic material may induce premature failures of the pavement structure or generate adherence distresses such as cracking or slipping of the surface layer [10].

In Colombia, the INVIAS establish a standard [11] emulsion application rate, between 0.3 l/m² to 0.5 l/m², hardly meet in field where this rate is set directly under the auditor guidelines. Moreover, these application rates are rarely set in accordance to the adhesive properties of the materials being applied. Thus, the aim of this study is to analyze the effect of the inclusion of different types of additives in rapid set cationic emulsions applied under different rates (0.33 l/m², 0.50 l/m² and 0.65 l/m²), over the shear resistance of a tack coat. This study seeks an impact in the area of roads infrastructure in Colombia, as it can be implemented as a guide to conduct proper construction processes that would lead to more durable pavement structure.

2. Materials and methodology

2.1. Materials

Metropolitan For this research, the adhesive properties of tack coats made of four different rapid set cationic emulsions are studied. Three different mixtures are used to simulate the surface layer and an asphaltic base, two conventional HMA mixtures and one rubberized asphalt concrete (RAC) mixture.

The granular material of the different mixtures is obtained in areas around Bogotá, Colombia. This material is mainly of calcareous origins and its properties are illustrated in Table 1, where it can be seen that the material being used meets all the ideal physical properties to be used in asphalt mixtures. Three different gradations are used to fabricate two conventional Colombian surface layer mixtures and one modified asphaltic based. For the surface layer mixtures, conforming to the national requirements [2], two gradations with different maximum aggregate size (MAS) are used, one with a MAS of 12 mm (HMA-12), and the other one with a MAS of 19 mm (RAC). Regarding the asphaltic base mixture, mixture with a gradation with MAS of 20 mm is fabricate (HMA-20), conforming also with the national requirements [2].

An asphalt binder with penetration of 60-70 (1/10 mm) is used to fabricate the conventional HMA mixtures, while the RAC mixture is fabricated with an asphalt modified with recycled rubber grain. As it can be seen in Table 2, both asphalt binders meet the National requirements to be used in pavements under high levels of traffic loads [2]. Four different rapid set cationic emulsions (CRS) are used as tack coats in this study. Emulsions of type CRS-1, CRS-1m, CRS-1D and CRS-1N were used, where 1 is referred to low viscosity emulsions, m to modified, D to the existence of a solvent to reduce the viscosity of the emulsion and N to the addition of nanomaterials to modify the emulsion properties. Their physical

properties were studied in order to determine their suitability to be used as tack coats, this information can be found in Table 3.

Table 1. Physical properties of the stone aggregate.

Test	Standard	Unit	Result	Requirement
Sand equivalent value	[12]	%	66.0	min 55.0
Abrasion in Los Angeles machine	[13]	%	21.0	max 50.0
Form index	[14]	-	0.7	min 0.5
Soundness of aggregates by use of magnesium sulfate	[15]	%	7.0	max 12.0
Adhesion of aggregate to bituminous material	[16]	Qualitative	Satisfactory	Satisfactory
Bulk specific gravity	[17]	g/cm ³	2.6	-
Bulk specific gravity saturated-surfaced-dry	[17]	g/cm ³	2.6	-
Absorption	[17]	%	0.8	-
Specific gravity of fine aggregates	[18]	g/cm ³	2.6	-

Table 2. Physical characteristics of 60-70 and RAC binders.

Test	Specification	Unit	Binder 60-70			RAC binder		
			Min	Max	Value	Min	Max	Value
Tests on the original asphalt								
Penetration (25 °C, 100 g, 5 s)	[19]	0.1 mm	50.0	70.0	51.1	40.0	70.0	44.0
Penetration index	[20]	-	-1.5	+0.7	-0.67	-	-	-
Softening point	[21]	°C	46.0	-	52.0	52.0	-	76.0
Specific gravity	[22]	-	-	-	1.022	-	-	-
Viscosity a 177 °C	[23]	cP	57.0	285.0	66	1500	3000	2500.0
Flashpoint	[24]	°C	235.0	-	338	230	-	248.0
Ductility (25 °C, 5 cm/min)	[25]	cm	100.0	-	>105	-	-	-
Tests on the asphalt residue after aging RTFOT								
Loss of mass	[26]	%	-	0.50	0.10	-	1.00	0.63
Penetration, in % with respect to the original penetration	[19]	%	55.0	-	81.0	65.0	-	76.0
Increase of softening point	[21]	°C	-	8.0	7.5	-	-	-

Table 3. Physical properties of the asphalt emulsions used in the irrigation of the league.

Test	Standard	Specification		Unit	CRS 1	CRS 1m	CRS 1D	CRS 1N
		min	max					
Asphalt content	[27]	60.0	-	%	60.1	61.8	21.3	21.3
Saybolt furol viscosity at 50 °C	[28]	20.0	100.0	SSF	23.0	27.0	13.0	13.0
Water content in volume	[27]	-	40.0	%	40.0	39.0	79.5	80.1
Sedimentation storage stability	[27]	-	5	%	2.7	1.3	7.5	7.2
Distillation - residual asphalt content	[27]	60.0	-	%	60.0	61.0	20.5	20.5
Distillation - solvent content	[27]	-	3.0	%	2.5	1	2.5	2.5
Sieving - retained sieve 20	[27]	-	0.1	%	1.6E-2	2.0E-2	1.1E-2	1.1E-2
Sodium dioctyl sulfosuccinate break	[27]	40.0	-	%	63.0	69.0	72.0	72.0
Particle charge	[27]	Positive	-	-	Positive	Positive	Positive	Positive
pH	[27]	-	6.0	-	2.3	2.1	1.9	1.9
Tests on the distillation residue								
Penetration (25 °C, 100 g, 5s)	[19]	60.0	100	0.1 mm	72.0	65.0	99.0	99.0
Ductility (25 °C, 5 cm/min)	[25]	100.0	250	cm	150.0	59.2	150.0	150.0
Solubility in trichloroethylene	[27]	40.0	-	%	99.0	25.0	99.0	99.0
Elastic recovery by torsion at 25 °C	[29]	97.0	-	%	-	29.0	-	-

2.2. Experimental plan

The methodology of the investigation was divided into three stages; (I) In the first stage the design of the three asphalt mixtures (*i.e.* HMA-20, HMA-12 and RAC) is conducted with the Marshall methodology. The HMA-20 mixture was used as the asphaltic base and the HMA-12 and RAC mixtures were used as surface layers; (II) In the second stage two structural packages are fabricated, which are composed by an asphaltic base mixture and a surface layer mixture bonded together with a tack coat. The first structural package is composed by a HMA-20 asphaltic base and a HMA-12 surface layer, while the second is composed by a HMA-20 asphaltic base and a RAC surface layer. To evaluate the adhesive performance of different emulsions used as tack coat in the two structural packages, four types of emulsions are used: CRS-1, CRS-1m, CRS-1D and CRS-1m. For each structural package, the four emulsions were applied with three different rates: 0.33 l/m², 0.50 l/m² and 0.65 l/m²; (III) finally, in the third stage, the “Laboratorio de Caminos de Barcelona (LCB)”, Spain, shear test was carried out with the objective of determine the shear resistance of the bonding interface.

45 Marshall cylinders were manufactured, corresponding to the three asphalt mixtures (HMA-20, HMA-12 and RAC) with 5 different asphalt contents. The cylinders were compacted with 75 blows per side to reach a dimension of approximately 4” in diameter and 2.5” in height, following the guidelines established by the national standards to conduct the Marshall test [30]. The Marshall test was carried out on all the samples in order to obtain the volumetric composition of the mixtures (Air void content Va, void content in the mineral aggregate VMA and voids filled with asphalt VFA) and the resistance of the material under monotonic load (stability S) at 60 °C. Based on the results obtained in this phase, the optimum percentage of asphalt to be used was chosen by type of mixture (HMA-20, HMA-12 and RAC) for the execution of the subsequent phases.

Two structural packages are fabricated, one composed of a HMA-20 and HMA-12 mixture and the second by a HMA-20 and a RAC mixture. For the structural package fabrication, the asphaltic base (HMA-20) is compacted with 100 blows per side in a mold with a diameter of 101.6 mm and a height of 177.8 mm. 24 hours after compaction, a tack coat is applied over one of the faces of the resultant cylinder; being controlled by gravimetric proportions. Moreover, a 15 minutes set time of the emulsion is established based on the coloration phenomenon. Once the emulsion has set, the correspondent surface layer (HMA-12 or RAC) is compacted over the asphaltic base, with 50 blows in the top face. The resultant structural package has a 2:1 height relation of the asphaltic base and surface layer mixture, respectively.

According to the Spanish standard, the LCB shear test is used to measure the adhesion resistance in the interface of composite specimens [12,13]. The test consists on a simply supported specimen placed horizontally over two rectangular beams, which is subjected to flexion by a centric load capable of producing a constant stress on the plane of weakness (*i.e.* plane of union of layers). The test is controlled by a deformation rate of 1.27 mm per minute and conducted at an intermediate temperature of approximately 20 °C. The necessary load to separate both materials (*i.e.* base and surface layer) resulting from the test is divided by 2 times the cross-sectional area of the cylinder to compute the tangential tension (τ) in the interface of both specimens.

3. Results

The volumetric and strength parameters obtained after conducting the Marshall methodology for each of the three mixtures studied are reported in Table 4. By means of the results, it is possible to conclude that all the asphalt mixtures meet the minimum requirement in terms of resistance in accordance to the national standards [2,3]. Figure 1 illustrates the impact of the application rate of the tack coat on the magnitude of τ of each structural package interface. According to the results, it can be said that,

- ✓ The optimum application rate for the four emulsions used (CRS-1, CRS-1D, CRS-1m and CRS-1N) respectively is 0.5 l/m². For higher or lower application rates than 0.5 l/m² a reduction of adherence within the asphalt layers can be evidenced.
- ✓ In terms of the materials being used as the base and surface layers, it is observed that all the tack coats (*i.e.* the four emulsions studied) have a higher shear resistance when the surface layer is

composed by a HMA-12 mixture in comparison to the structural package using a RAC mixture. This can be due to the gradation and materials of each mixture, as HMA-12 having a higher percentage of fine aggregates and a conventional binder covering them, presents a smoother surface than the RAC, mixture that have coarser aggregates and thicker asphalt film covering them due to the high viscosity of rubber asphalt binders. Therefore, the high roughness of the RA mixtures (RAC) generates a higher consumption of asphalt emulsion and consequently lower contact points and lower shear resistance of the tack coat.

Table 4. Marshall design strength and volumetric parameters of the asphalt mixtures.

Parameters	HMA-12		HMA-20		RAC	
	Specification	Result	Specification	Result	Specification	Result
Marshall stability (kg)	Min. 900	1435	Min. 900	1335	Min. 900	1370
Marshall flow (mm)	2.0-3.5	3.1	2.0-3.5	3.0	2.0-3.5	3.2
E/F (kgf/mm)	300-600	463	300-600	445.0	300-600	550
Specific gravity bulk	NA	2.2	NA	2.2	NA	2.2
Air void content-Va (%)	4.0-6.0	4.8	4.0-6.0	4.7	4.0-6.0	4.9
Void in mineral aggregates-VAM (%)	Min. 15.0	16.4	Min. 14.0	16.0	Min. 14.0	17.6
Voids filled with asphalt-VFA (%)	65-75	69	65-75	69	65-75	71
Asphalt content (%)	NA	5.8	NA	5.6	NA	7.3

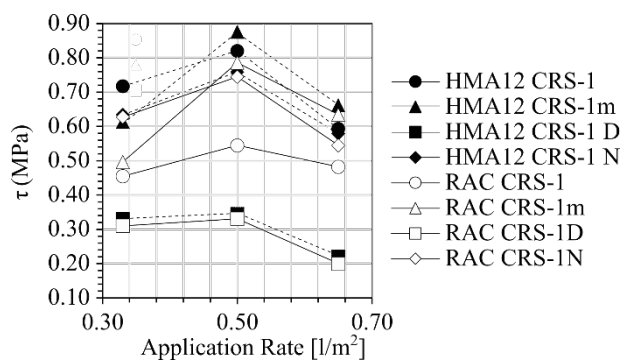


Figure 1. Shear resistance of the tack coat for each application rate studied.

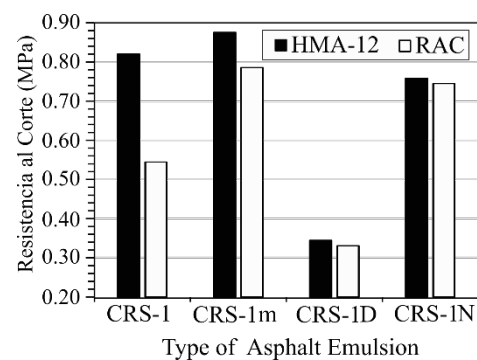


Figure 2. Performance of the type of asphalt emulsion in the cut resistance.

Analyzing the effect of the type of asphalt emulsion being used over the shear resistance of the tack coat in the different structural packages, as show the Figure 2, it can be said that the modified one (CRS-1m) presents the best adhesion performance within all the emulsion studied either when the asphaltic base (HMA-20) is being bond to the conventional (HMA-12) or the modified (RAC) surface layer. From Figure 2, it can also be seen that when the tack coat is fabricated with a diluted emulsion the shear resistance of the interface of the structural package is very low, with values around 0.3 MPa; meaning that the tack coat would have very poor adhesive properties and the probability of the pavement to failure is the highest within the materials studied. Additionally, these behaviors can be due to the percentage of asphalt content of the emulsion, as the shear resistance of the tack coat is directly proportional to the residual asphalt contents of the emulsion. As it can be seen in Table 3, CRS1-m has approximately 61% of residual asphalt, while CRS-1D has only 20%.

4. Conclusions

In the present study the adherence and physical properties of different tack coats, used to create a strong bond within an asphaltic base layer and two different surface layers, are evaluated in terms of shear resistance under the LCB test. Tack coats are fabricated with four different rapid set cationic emulsions and are applied under three different rates. Based on the results obtained, it can be concluded that the tack coat application rate that provides the best resistance in terms of adhesion is 0.50 l/m² in comparison

to a rate of 0.33 l/m² or 0.65 l/m². Overall, lower or higher application rates than 0.50 l/m² leads to adhesion problems within the pavement layers allowing the emergence of structural and functional pathologies in the pavement.

On the other hand, it can be concluded that tack coats of modified emulsions, when applied at a rate of 0.5 l/m², presents the best performance in terms of shear resistance when compared to conventional emulsions or when a solvent or nanomaterial are added to it. It was also found that the shear resistance of the material depends directly on the percentage of residual asphalt of the emulsion.

Finally, with this study it can be demonstrated that for the same asphaltic base the bonding with a surface layer mixture with finer gradation and a conventional asphalt binder is better in terms of adherence than the bonding generated with surfaces of coarser mixtures fabricated with rubber-asphalts. Finer gradations present a higher superficial area, which lead to have higher contact points with the tack coat.

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