Comprehensive Performance Evaluation of Asphalt Surface Treatments

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ABSTRACT: Pavement preservation is of critical importance to the overall service life of a pavement. One of the most cost-effective preservation treatments is the asphalt surface treatment (AST). The overarching goal of this study is to research ways to improve the performance of ASTs in North Carolina by investigating three major components of AST construction: the aggregate, the emulsion, and the rolling procedure. To achieve this goal, the Vialit test, flip-over test, third-scale model mobile loading simulator (MMLS3), bleeding test, and embedment depth measurements are employed to evaluate the performance of several ASTs. First, the effects of fine content and aggregate gradation on aggregate retention are evaluated. Results suggest that the aggregate loss increases with the increase in fine content and that the aggregate gradation plays a critical role in the aggregate retention performance regardless of the type of aggregate. Second, the performance of polymer-modified emulsion (PME) in ASTs is evaluated. Based on the test data obtained from this study, it is concluded that PME enhances the aggregate retention performance and does so more significantly in the early stages of service life and at low temperatures. Finally, the rolling procedure is evaluated to determine the optimal rolling protocol for AST construction based on aggregate retention performance and aggregate embedment depth. The findings suggest that proper rolling protocol could significantly enhance the AST's service life and help to prevent aggregate loss and bleeding.

KEY WORDS: Asphalt surface treatment, MMLS3, aggregate retention, polymer modified emulsion, rolling pattern

1 INTRODUCTION

Asphalt surface treatments (ASTs) are typically used in the pavement preservation program of the North Carolina Department of Transportation (NCDOT). ASTs provide a durable and functional pavement surface that serves as a highly economical highway maintenance option when constructed properly. For example, in North Carolina in 2006, approximately 8% of roadway pavement expenditures were spent on surface treatment construction. That percentage constitutes about 50% of the miles paved in the State. This paper presents the results of an evaluation of AST performance. The findings suggest ways to significantly enhance AST performance by helping to prevent aggregate loss.

The AST combines a layer of emulsion with a thin layer of aggregate. AST construction consists of three steps: spraying emulsified asphalt, spreading a layer of aggregate, and finishing with rolling. This paper presents the research efforts at North Carolina State University (NCSU) to improve the performance of ASTs in North Carolina by using better materials in the first two steps and/or by using an optimal rolling protocol.

2 MATERIALS AND SPECIMEN FABRICATION

The selection of the materials, i.e., aggregate and emulsion, used for this study is based on the most commonly used materials for AST construction in North Carolina. Two types of aggregate are used: expanded slate lightweight aggregate with a 5/16 in. Nominal Maximum Aggregate Size (NMAS) and No.78M graded granite aggregate. Also, two types of emulsion, a nonmodified emulsion (CRS-2) and a PME (CRS-2L) modified with latex, are used in this study. All specimens were fabricated both in the laboratory and in the field based on procedures designed at North Carolina State University. The detailed test procedures are described in Lee et al. (2006) and Lee et al. (2009).

3 EXPERIMENTAL METHODS

Five basic test methods are employed in this study to evaluate the performance of several ASTs in North Carolina. They are: 1) the Vialit test, 2) flip-over test (FOT), 3) third-scale model mobile loading simulator (MMLS3), 4) bleeding test, and 5) embedment depth measurements. These tests and measurements are used to investigate three major components of AST construction: the aggregate, the emulsion, and the rolling procedure. A brief description of these experiments follows. A more thorough description of each test can be found elsewhere (Lee et al. 2006, Kim et al. 2008, and Lee et al. 2009).

3.1 Vialit Test

The Vialit test evaluates the adhesion performance between the aggregate and the emulsion and thus is used to evaluate the aggregate retention performance. The Vialit test was developed by the French Public Works Research Group and standardized in British Standards (BS 12272-3). In the United States, the California Department of Transportation uses this test to indicate aggregate retention for ASTs. Samples are weighed before and after a ball drop to calculate the percentage of aggregate loss using Equation (1).

$$Aggregate\,Loss\ (\%) = \frac{W_{B,aggregate} - W_{A,aggregate}}{W_{B,aggregate}} \times 100 \quad (1)$$

,

where $W_{B,\ aggregate}$ and $W_{A,\ aggregate}$ are the weights of the aggregate on the AST specimen before and after the test, respectively.

3.2 Flip-Over Test

FOT specimens were fabricated on 25.4 cm x 25.4 cm felt paper. The samples fabricated at the test sections were stored at room temperature (25°C) and were fully cured at 35°C for 24 hours before the test. Each specimen was turned vertically, and any loose aggregate was removed by lightly brushing the specimen. The aggregate loss was calculated using Equation (1).

3.3 MMLS3 Test

Lee et al. (2006) developed a test protocol for the performance evaluation of ASTs using the MMLS3 to measure aggregate retention performance. A brief outline of the test method is as follows. First, a specimen is cured for 24 hours at 35°C and 30 ± 3% relative humidity (RH) before testing, as specified in the ASTM D 7000 (ASTM 2004). The specimen dimensions are 17.8 cm wide and 35.6 cm long. This design is necessary because it was found from former research (Lee et al. 2006) that the aggregate that is lost under MMLS3 loading falls onto untrafficked areas, causing errors in the aggregate loss calculation. The specimen is mounted onto a thin steel plate fastened to a steel base plate and then measured before and after MMLS3 loading to determine the aggregate loss. MMLS3 loading is applied after a 3-hour temperature preconditioning period at 25°C. The aggregate loss during the initial traffic loading in the field (normally occurring within a day) is measured after one wandering cycle of MMLS3 loading for 10 minutes. Then, additional MMLS3 loading is applied, and the weight of the specimen is measured at the end of a 2-hour loading period to evaluate the long-term aggregate retention performance of the AST under traffic (Lee et al. 2006).

3.4 Bleeding Test

Lee et al. (2008) developed a test protocol for the bleeding performance of AST specimens that could be quantified employing Digital Image Processing (DIP). Before and after the MMLS3 bleeding test, the AST specimen surface is scanned into an 8-bit grayscale digital image that consists of a single plane of pixels.

3.5 Embedment Depth Measurement Test

NCSU developed a modified sand circle method based on the *Roads and Traffic Authority Test Method T 240: Road Surfaces Texture Depth* (Roads and Traffic Authority 2006) that measures the texture depth of a coarse road surface. The modified sand circle method adopts the use of a loose unit mass of sand (Roads and Traffic Authority 2001) to calculate the average texture depth between the bottom of the pavement surface voids and the top of the surface aggregate particles. The detailed test procedure is described in Kim et al. (2008).

4 RESULTS AND DISCUSSION

4.1 Effects of Fine Content and Aggregate Gradation

Figure 1 presents the MMLS3 test results for different fine contents for granite and lightweight aggregates. In general, the aggregate loss increases as the number of wheel loads increases and as the fine content increases. As can be seen in this figure, most of the light-weight aggregate loss occurs during the initial trafficking, whereas continuous aggregate loss is shown for the granite. In general, the light-weight aggregate retains better than the granite. Moreover, the effect of additional fines on aggregate loss is much less significant with the light-weight than the granite aggregate.

The effect of gradation on AST performance was evaluated by the MMLS3 test and the FOT. The majority of the aggregate particle sizes were between 1/4 in. and the No. 8 sieve for the granite and between 3/8 in. and No. 8 for the light-weight aggregate. The aggregate gradations in both aggregates were changed by removing the aggregate passing the No. 8 sieve, making the gradations of both aggregates more uniform.

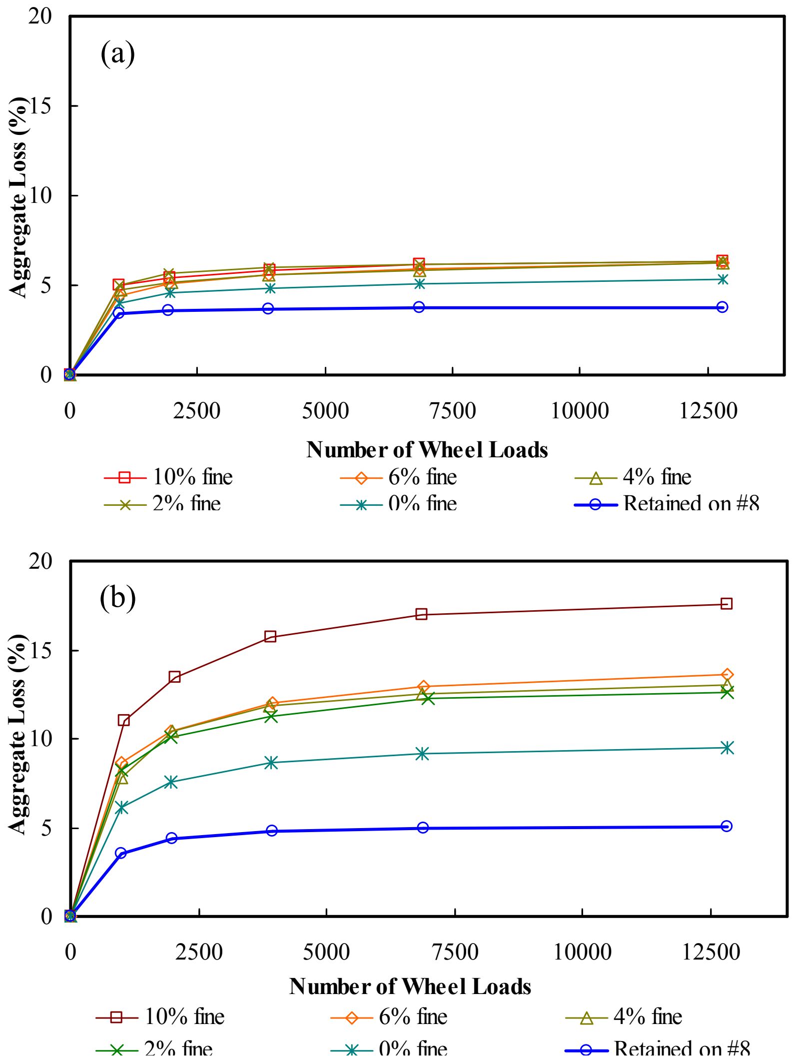

Figure 1: Aggregate loss performance on effect of fine content and gradation: (a) light-weight aggregate; (b) granite

The effect of the aggregate gradation on the aggregate loss in the MMLS3 test is displayed in Figure 1. This figure shows that the removal of aggregate passing the No. 8 sieve causes a reduction in aggregate loss for both aggregates, with a much more significant effect on the granite. The reason for this reduction in aggregate loss is that the removal of aggregate passing the No. 8 sieve makes the aggregate gradation more uniform. A similar trend is also seen from the results of the FOT. Another important observation to be made from this figure is that the aggregate loss from the modified gradation is about the same for both the granite AST and light-weight AST. Therefore, it can be concluded that the lower aggregate loss, shown in Figure 1 for the light-weight AST with the original gradation, has much more to do with the uniform gradation in the light-weight aggregate than the fact that it is light-weight, that it has a higher FI (Flakiness Index), or that it has a higher absorption value.

4.2 Performance of Polymer-Modified Emulsion

4.2.1 Adhesion Behavior at Different Curing Times

The adhesion development of the CRS-2 and CRS-2L emulsions was investigated as a function of curing times using the Vialit test. The Vialit samples were cured at 35°C and for 1, 2, 3, 12 and 24 hours. In total, seven tests were performed at each curing time for a total of 35 tests per emulsion type. The average aggregate loss was calculated from the seven replicates at each curing time and is plotted in Figure 2. Figure 2 shows that aggregate loss decreases as the curing time increases, regardless of emulsion type. Notice that in this plot the error bars are shown to represent the highest and lowest percentages of aggregate loss measured for a particular condition. Figure 2 can be seen at the 2-hour curing time. The percentage of aggregate loss of the CRS-2L emulsion is less than 10% of the maximum allowable aggregate loss; however, the average aggregate loss of the CRS-2 emulsion is still over 10%. This finding indicates that the CRS-2L emulsion achieves proper adhesion within 2 hours, which satisfies the maximum allowable aggregate loss specified in the Alaska AST design guide. However, 2 hours is not enough time for the CRS-2 emulsion to meet the Alaska AST criterion. All average aggregate loss values measured for samples that were cured for more than 3 hours (3, 12, and 24 hours) are below 10%. Also, the difference between aggregate loss for the CRS-2L and CRS-2 emulsions clearly is reduced after 3 hours. The overall trend, i.e., that the aggregate loss of the CRS-2L is less than that of the CRS-2, as seen in Figure 2, indicates that the CRS-2L emulsion enhances the aggregate retention performance, and does so more significantly in the first three hours. The largest difference in aggregate loss (i.e., a 12% difference) between the CRS-2 emulsion and CRS-2L emulsion occurs at 2 hours, as seen in Figure 2. Figure 2 (a) shows the data in the first three hours with the 10% maximum allowable aggregate loss. The CRS-2L emulsion satisfies this criterion after 1 hour 30 minutes, and the CRS-2 emulsion reaches 10% of aggregate loss after 3 hours of curing. Figure 2 (a) thus indicates that the CRS-2L emulsion exhibits a faster change in adhesion than the CRS-2, which reduces aggregate loss during early curing times. Thus, the benefits of fast and improved adhesion seen with the CRS-2L emulsion are manifest in: a reduction in the amount of aggregate loss during early curing times, less curing time needed to obtain the desired adhesion between the asphalt and aggregate, and the ability to allow traffic safely on the freshly constructed road sooner.

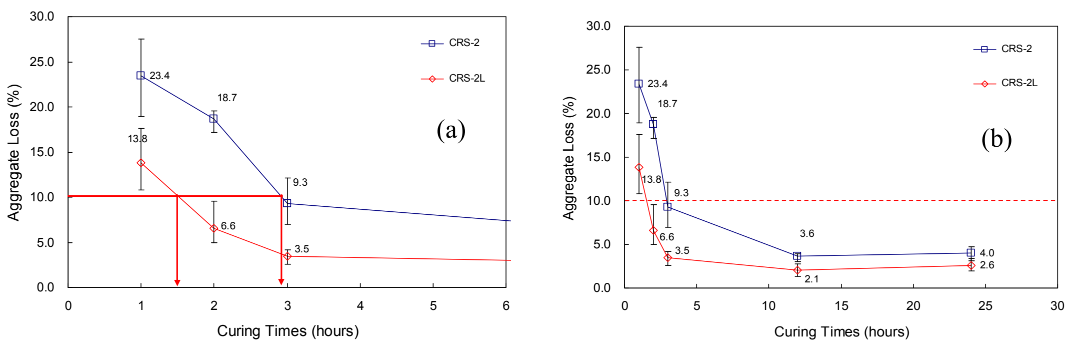

Figure 2: Aggregate loss results from the Vialit test as a function of curing times: (a) first three hours, and (b) 24 hours

4.2.2 Adhesion Behavior at Low Temperatures

One of the main failures of ASTs is aggregate loss when the temperature drops during fall and winter (Wade et al. 2001). Therefore, the performance of ASTs using the two emulsion types, CRS-2 and CRS-2L, was evaluated at low temperatures. Two sets of the Vialit samples were stored at -20°C (below freezing) and 5°C (above freezing) for 24 hours to simulate aggregate retention performance under cold weather conditions. These two temperatures were chosen because (1) they represent the temperatures below and above the freezing temperature, and (2) they are the temperatures that the available refrigerator and freezer could provide. The temperature of -20°C is much lower than the lowest temperature reached in North Carolina; however, because only one freeze cycle was used in the testing, the actual below freezing temperature was not deemed too critical. The aggregate loss was calculated using Equation (1) and is presented in Figure 3 for the two types of emulsions. The results from the 25°C testing are also presented in this figure for comparison. It can be seen that the use of PME significantly reduces aggregate loss at low temperatures (almost three times less aggregate loss than for the nonmodified emulsion). The percentages of aggregate loss of the CRS-2 emulsion at 5°C and -20°C are over the maximum allowable aggregate loss of 10%, whereas the values for the CRS-2L emulsion are below the maximum allowable aggregate loss of 10%. These findings indicate that the CRS-2L emulsion is more effective in enhancing aggregate retention performance at low temperatures (below 5°C).

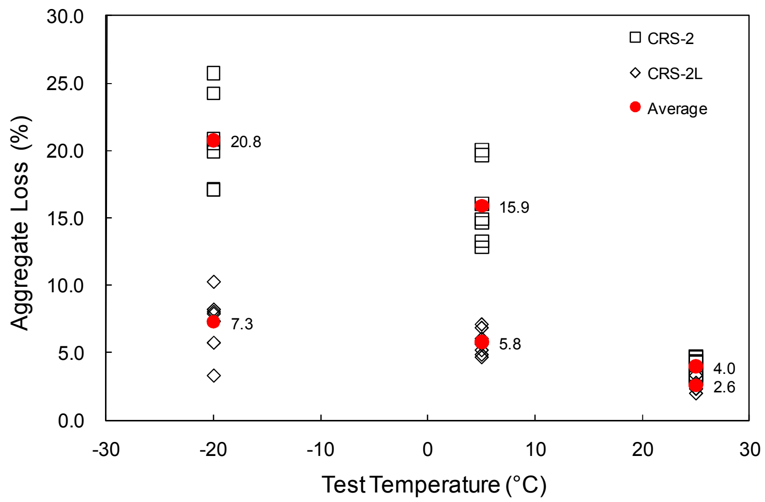

Figure 3: Aggregate loss results for the specimens subjected to low temperatures

4.3 Determination of the Optimal Rolling Protocol

4.3.1 Determination of the Optimal Number of Coverages

In order to implement an effective number of coverages for the AST, six test programs were completed to evaluate the performance of two seal types (single seal and double seal) under three different numbers of coverage (1, 3, and 5). Table 1 summarizes the percentage of average aggregate loss obtained from three aggregate retention tests and the aggregate embedment depth using MMLS3 and FOT samples.

The decrease in aggregate loss versus the number of coverages is clearly shown in Table 1. Also, the change in aggregate embedment depth as a function of the number of coverages indicates that the optimal number of coverages is three coverages for the single seal. A statistical analysis program, ANOVA, as shown in Table 1, was conducted to determine if the differences found in the means are statistically significant. The differences among the three groups are significant because the p-values are greater than the alpha level of 0.05, with the exception of the MMLS3 result for the double seal. The MMLS3 test of the double seal indicates no significant differences among the three different coverages. It should be noted that the aggregate in a multiple seal layer will become rearranged and compacted under traffic in order to reach a theoretical optimal packing arrangement (Ball et al. 2005). Due to the compaction mechanism of the double seal under MMLS3 loading, the MMLS3 does not make a difference to the percentage of aggregate loss. Considering these results and the economic factors involved in rolling time, three coverages seems to be the optimal number of coverages for the double seal.

Table 1: Summary of Average Percentage of Aggregate Loss and Embedment Depth

Test Method	AST Type	Number of Coverages			ANOVA
		One	Three	Five	P-value
Vialit (%)	Single	16.9	6.7	4.8	0.0015
	Double	9.1	7.4	5.4	0.0583
FOT (%)	Single	16.0	10.6	6.3	0.0813
	Double	15.7	10.5	12.1	<0.0001
MMLS3 (%)	Single	10.9	7.2	3.2	0.0043
	Double	14.3	13.7	14.0	**0.8664**
Embedment Depth (mm)	Single (FOT)	0.81	1.76	1.84	-
	Single (MMLS3)	0.95	1.42	1.56	-

4.3.2 Optimal Rolling Patterns

In order to find optimal rolling patterns, five different rolling patterns were evaluated, as described in Kim et al. (2008). Based on the results found in this study, the rolling pattern is closely correlated to the delay in rolling time between the aggregate spreading and the rolling. The effect of the delayed rolling time is shown Figure 4 in terms of aggregate retention performance using MMLS3 testing. The optimal delayed rolling time changes according to the water content of the aggregate. Three rolling patterns have been selected for further study to evaluate the delayed rolling time for these patterns.

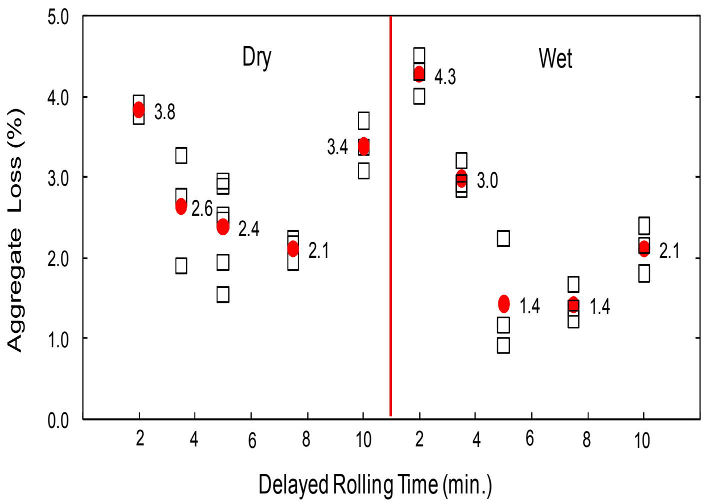

Figure 4: Aggregate loss results as a function of delayed rolling time using dry and wet aggregate (0% and 2% water content, respectively)

These three patterns are denoted as Case A, Case B, and Case C in Figure 5. The Case A pattern was selected because it is commonly used by several Divisions of the NCDOT. This pattern uses the pneumatic tire roller in the front and the combination roller in the back. Case B has an advantage over Case A in that the entire lane width is subjected to rolling at the same time using the combination rollers. Case C uses two pneumatic tire rollers in a staggered pattern at the front, which yields more consistent rolling along the lane width, followed by a combination roller. The AST pavement construction schedule is simulated for these three cases to determine the delayed rolling time for each of these patterns. The primary factor to be considered in the evaluation of different rolling patterns using different section lengths is the time difference between the end of the aggregate spreading and the end of the rolling.

Four different section lengths were used in the simulations: 365.8, 457.2, 609.6, and 762 meters per section. These section lengths cover a range of section lengths that can be constructed by a fully loaded aggregate spreader without stopping. The calculations were made using typical AST construction equipment speeds measured at the AST construction site. The construction sequence and related times are plotted in a bar chart format in Figure 5 (b)~(d). Figure 5 (b) shows the construction schedule for Cases A and C. Because the types of rollers involved in Cases A and C are the same, and the second roller in the front row of Case C adds minimal additional time to the overall rolling operation, their construction schedules are considered to be the same.

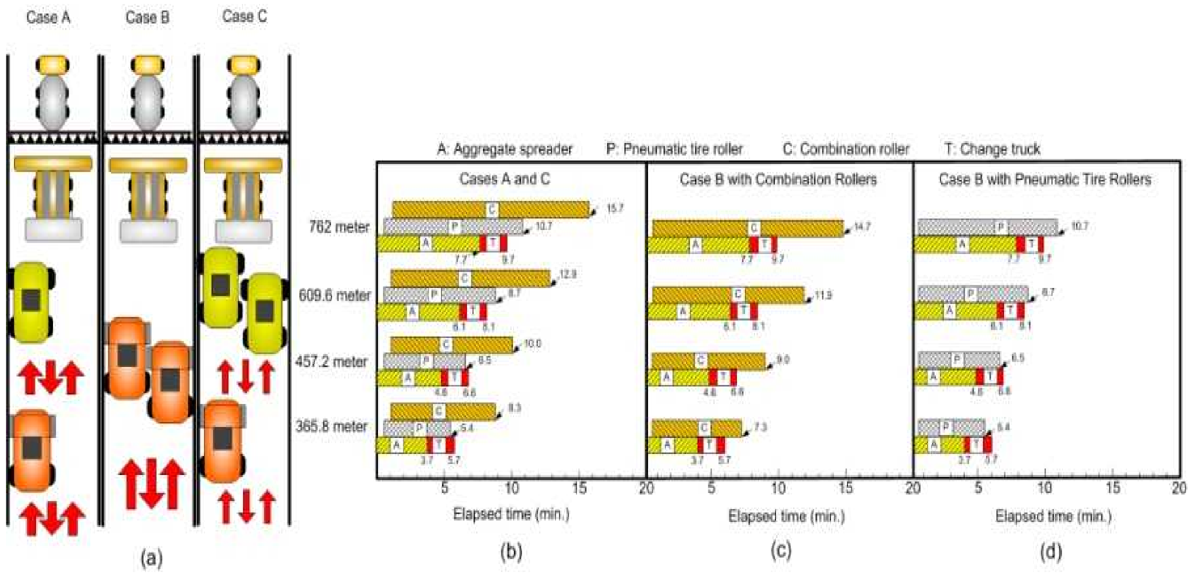

Figure 5: (a) Rolling patterns using two and three rollers selected for the final evaluation, (b) construction time for Cases A and C, (c) construction time for Case B using two combination rollers, and (d) construction time for Case B using two pneumatic tire rollers

Figure 5 (c) and (d) display the construction schedules for Case B using two combination rollers and Case B using two pneumatic tire rollers, respectively. Case C with a 609.6 m section length is used to calculate the rolling time, as seen in Figure 5. According to the calculation, the aggregate spreader spreads the aggregate for the entire section length of 609.6 m within 6.1 minutes. With a 30-second delay between the aggregate spreader and the first roller, the rolling by the second roller, i.e., the combination roller, is completed within 12.9 minutes. Therefore, in this case, the time delay between aggregate spreading and rolling for the last portion of the section is 6.8 minutes (i.e., 12.9 minus 6.1 minutes).

4.3.3 Coverage Distribution for Multiple ASTs

In this section, the effect that rolling the bottom layer of multiple seals has on aggregate retention performance is evaluated by conducting laboratory aggregate retention tests on field-fabricated samples. These tests include the FOT, the Vialit test, and the MMLS3 test. The aggregate retention test results, as seen in Table 2, clearly demonstrate the benefit of rolling the bottom layer of double seals, but not so much for triple seals. The roughness analysis, based on the digital imaging of double seal cross-sections, suggests that the rough surface of the bottom layer due to lack of rolling affects the roughness of the layer immediately above the bottom layer and, thus, the aggregate loss. It is therefore recommended to roll the bottom layer of double seals to reduce aggregate loss. However, for triple seals, rolling the bottom layer is not required, considering the cost and time required to roll the bottom layer and the minimal improvement in aggregate retention performance. The overarching principle for multiple ASTs is that one rolling coverage of the layer immediately below the top layer would improve the aggregate retention performance of the top layer.

Table 2: Comparison of Aggregate Retention Test Results

Test Method	Percentage of Aggregate Loss					
	Double Seal			Triple Seal		
	Zero	One	Difference	Zero	Two	Difference
Vialit	14.4	7.8	6.6	7.4	5.3	2.1
FOT	32.0	22.6	9.4	9.0	11.5	2.6
MMLS3	27.1	19.7	7.4	10.1	12.1	2.0

5 SUMMARY AND CONCLUSIONS

An overall evaluation of AST performance was conducted based on aggregate retention, bleeding, and embedment depth in order that the results may lead to extending the service life and improving the construction procedures for ASTs. It is found that aggregate gradation plays a critical role in the aggregate retention performance regardless of the type of aggregate. Also, the increase in fine content increases the aggregate loss; however, the amount of fine has much less an effect on aggregate loss in the lightweight AST with a more uniform gradation than in the granite AST with a less uniform gradation. Specifically, the most critical factor in minimizing aggregate loss in ASTs, regardless of aggregate type, is uniform gradation. For the rolling study, the optimal number of coverages, regardless AST type, is three, based on test results. Also, the double seal clearly requires rolling for the bottom layer; the triple seal does not. So, the rolling operation may be eliminated for the bottom layer. Based on overall rolling pattern results, Case B and Case C in Figure 5 are the patterns recommended for the use of two rollers and three rollers, respectively. Further, this paper shows that the benefits of fast and improved adhesion found in PME is manifested in: a reduction in the amount of aggregate loss during early curing times, less curing time needed to obtain the desired adhesion between the asphalt and aggregate, and the ability to allow traffic on the newly constructed road safely and sooner. PME improves the aggregate retention performance at low temperatures, such as those experienced in winter. The CRS-2L emulsion meets the criterion of 10% maximum allowable excess aggregate loss specified by the Alaska specifications at -20° and 5°C.

6 ACKNOWLEDGMENTS

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