Laboratory Evaluation of Long Term Effectiveness of Liquid Antistripping Agents

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ABSTRACT

The use of hydrated lime or other liquid anti-stripping agents (ASA) is the most common method to improve the moisture susceptibility of asphalt mixes. However, most laboratory test conditions used to evaluate the moisture susceptibility of the mixes are only for a short duration of time. This might not be a good representation of the field conditions (i.e., several months or years of service). Thus, a study to evaluate the effects of conditioning the mixes for longer duration was initiated. Also, another problem with the use of the liquid anti-stripping agents is their heat storage capability. This paper addresses these two issues, by preparing and testing mixtures made with fresh binder for indirect tensile strengths after conditioning the samples for 1, 7, 28, 90 and 180 days, and samples prepared from binder stored for 3 days at 163˚C after conditioning them for 1, 28 and 90 days. The results of this limited study indicated that hydrated lime and the liquid anti-stripping agents were equally effective for the mixes used in this research when conditioned beyond 1 day. In case of samples prepared from stored binder, there was no significant difference in the effectiveness of hydrated lime and the liquid anti-stripping agents even after conditioning for 1 day. Though it was observed that none of the ASA treatments performed better than others in case of samples prepared with stored binder, it was also observed that almost all mixes gave significantly similar wet ITS and TSR values as samples prepared from fresh binder.

Key Words: Antistrip additives, hydrated lime, moisture susceptibility, long term conditioning, hot mix asphalt stripping.

INTRODUCTION

The bond between the aggregate surface and the binder can be considered one of the most important factors influencing the integrity of a pavement. The bond between the aggregate and the binder should not only form in the initial states, but should also last the entire life of the pavement. Several mechanisms such as intrusion of water, hydraulic scouring due to tire pressure, and pore pressure within the matrix, film rupture, spontaneous emulsification, etc. can weaken and break the bond between the aggregate and the binder *(1)*. This phenomenon of breaking the bond between the aggregate and the binder is known as stripping. Stripping usually begins at the bottom of the pavement layer, and travels upwards gradually. A typical situation is the gradual loss of strength over the years, which causes many surface manifestations like rutting, corrugations, shoving, raveling, cracking, etc. *(2)*. This makes identification of stripping very difficult. Also, it may take many years for the surface indicators to show up. To prevent moisture susceptibility, proper mix design is essential. However, even with a proper mix design, if the mix is not compacted properly, it may still be susceptible to moisture. Thus, hot mix asphalt (HMA) should be tested in a situation where moisture can infiltrate into the air voids of the mixture. For this reason, the tests for moisture susceptibility are done on mixes containing 7 ± 1 percent air voids *(3)*. Of the many ways to prevent stripping in a pavement, the use of anti-stripping agents (ASAs) is the most common *(4)*. One of the most commonly used ASAs in the United States is hydrated lime *(5)*. Others include liquids like amines, di-amines, liquid polymers, and solids like Portland cement, fly-ash, flue dust, etc. Pavement contractors usually prefer liquid ASAs as they are relatively easy to use *(6)*. However, ASAs from an approved list of sources should not be blindly added as some ASAs are aggregate and asphalt specific, and therefore, may not be effective to be used in all mixes; they could even be detrimental at times. Thus, a proper study of the mix should be done by systematically testing the mix for moisture susceptibility using tests like indirect tension testing (ITS), Lottman's test, and boiling water test in the laboratory or other tests.

Several studies have been conducted to evaluate the effectiveness of hydrated lime as well as liquid ASAs *(6,7,8,9)*. However, most lab tests that are done to assess the moisture susceptibility of mixes assess only the short term effect of moisture on the mix. The ITS test, for instance, tests the moisture susceptibility of mixes after conditioning the samples in water for only 24 hours. This may not always be representative of the actual field conditions, and thus might be, in some cases, a misrepresentation of the actual moisture susceptibility of the pavement itself. In a previous study conducted by Lu and Harvey *(10)*, the long term effects of moisture on the effectiveness of the ASAs were studied. From the study, it was observed that most of the detrimental effects of moisture occurred in the first four months.

Another commonly reported problem associated with the liquid ASAs is their ability to be stored with hot binder over longer durations *(8,11,12)*. Typically, when amine based liquid ASAs are stored with bitumen at 140˚C to 190˚C, the nitrogen based functional groups of the ASAs react with the polar group of the bitumen to form compounds that do not have any anti-stripping capabilities. Another issue regarding the use of liquid ASAs is the possibility of being oxidized in the bitumen, and thus losing its anti-stripping capabilities *(12)*.

This research project evaluated the long term effects of moisture on the moisture susceptibility of several mixes. Some of the storage stability issues of the ASAs also have been investigated. Indirect tensile strength (ITS) tests were performed on samples conditioned in water for 1 day, 7 days, 28 days, 90 days, and 180 days, and the results were compared. A total of 600 samples were prepared and tested. To address the heat storage capability of the ASAs, the binder containing the ASAs was stored at 163˚C for 3 days, and was then used to prepare ITS samples that were tested after conditioning in water for 1 day, 28 days, and 90 days. A total of 360 samples were prepared with the stored binder.

OBJECTIVES

The main objective of the research was to determine the feasibility of using certain liquid ASAs in HMA mixtures and determine their effectiveness over longer durations. The specific objectives were as follows.

- Determining the physical properties of asphalt concrete specimens containing no ASAs, hydrated lime, or liquid ASAs.
- Comparing and analyzing, statistically, the physical properties of asphalt concrete containing particular ASAs to the other mixes.
- Comparing the effects of the physical properties of three aggregate sources and two binder sources containing particular ASAs.
- Comparing the effects of the physical properties of samples of a particular mix conditioned in water for 1 to 180 days.
- Compare the effects of storing the binder on the physical properties of the asphalt concrete specimens.

METHODOLOGY

The Superpave method of mix design was followed to determine the optimum binder content for each mix design. A total of 30 mix designs (2 binder sources × 3 aggregate sources × 5 different ASA treatments) were conducted. In the mixes containing hydrated lime as the ASA, 1% hydrated lime, by weight of the aggregate, was added in a slurry form. In the mixes containing liquid ASAs, 0.5% liquid ASA, by weight of the binder, was added to the binder. This ASA content selected based on the 0.25% - 0.75% recommended by the suppliers. The bulk specific gravity, maximum specific gravity, voids in mineral aggregate (VMA) and voids filled with asphalt (VFA) were obtained or calculated to determine the optimum asphalt content of all the 30 mixes.

For the moisture susceptibility study, a total of 960 samples were prepared. The samples were 150 mm in diameter and 95 ± 5 mm in height. These samples were subjected to SC-T-70 *Laboratory Determination of Moisture Susceptibility* testing procedures to obtain wet and dry ITS and tensile strength ratio (TSR) at ages of 1 day, 7 days and 28 days, 90 days and 180 days for mixes with fresh binder, and ages of 1 day, 28 days, and 90 days for mixes with stored binder *(13)*. The SC-T-70 is similar to AASHTO T283, the only difference being that the samples are not subjected to any freezing. The Statistical Analysis Systems (SAS) computer program was used to analyze the results.

MATERIALS AND EXPERIMENTAL PROCEDURES

The Superpave method of mix design for a 12.5 mm mix was followed for this study. Figure 1 illustrates the flowchart of the experimental design used in this laboratory investigation.

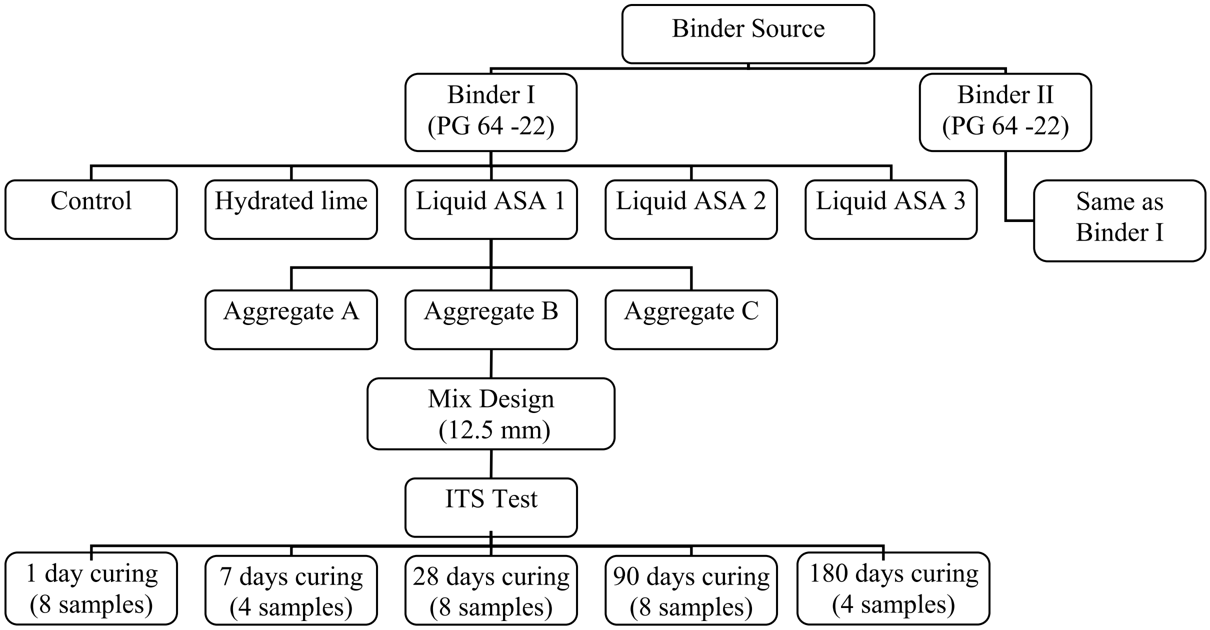


FIGURE 1 Experimental design.

The aggregates used in this study were obtained from three sources, denoted as A, B, and C. The types of aggregate received from each quarry consisted of #57, #789, Regular Screenings (RS), and Manufactured Sand (MS). Each type of the aggregate was randomly obtained from quarry stockpiles and transported to the laboratory. Aggregate A is prone to stripping, and Aggregate B is known to perform well against stripping.

The aggregates obtained were then tested for gradation as per the ASTM C 136, *Method for Sieve Analysis for Fine and Coarse Aggregate*. Table 1 contains the gradation properties of the aggregates used, and the percentage of each aggregate type used. Figure 2 shows the combined gradation of the three aggregate sources used.

TABLE 1 Aggregate Properties

Sieve Size (mm)	Gradation Range	Combined Gradation (% Passing)		
		Agg. A	**Agg. B**	**Agg. C**
38	100	100	100	100
25	100	100	100	100
19	98 – 100	99	100	100
12.5	90 – 100	94	94	94
9.5	74 – 90	89	84	85
4.75	46 – 62	49	49	51
2.36	25 – 41	30	39	32
0.150	4 – 12	6.6	8.5	8.1
0.075	2 – 8	3.34	5.12	5.01
Stone Type		**% Used in the mix**		
#57		9	11	30
#789		61	46	32
RS		20	17	20
MS		10	26	18
		Properties		
Aggregate Type		Micaceous Granite	Marble Schist	Granite
Bulk Specific Gravity		2.700	2.830	2.610
% Absorption, %		0.77	0.49	0.62
Los Angelis Abration Loss, %		52	23	26

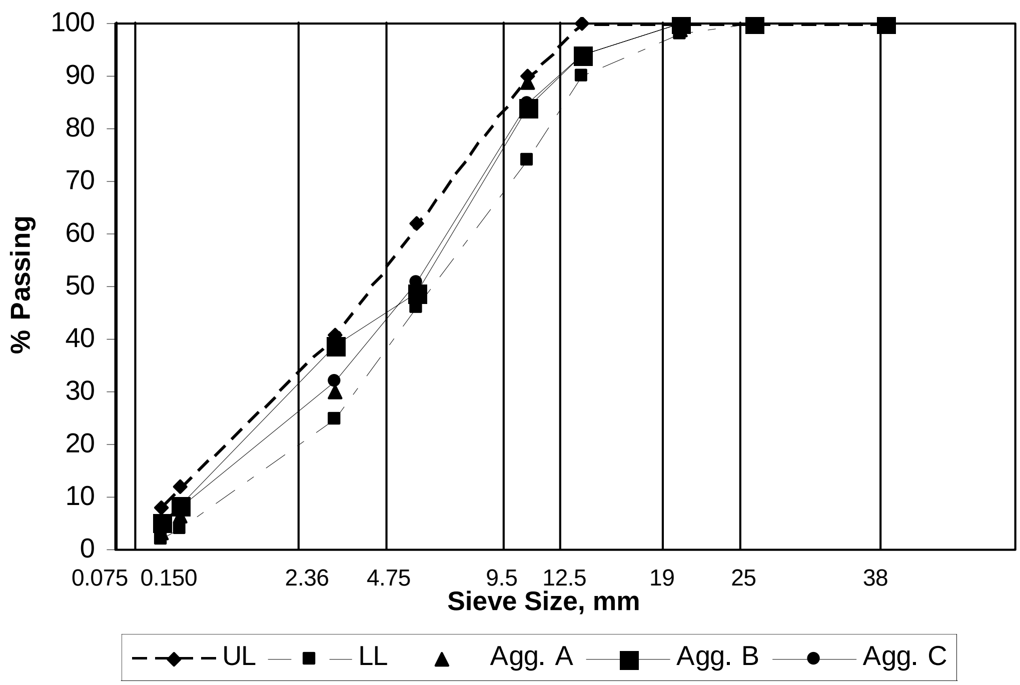


FIGURE 2 Aggregate Gradation.

Two different sources of binder were used in this project, both PG 64 -22, denoted as I (a mixture of crude sources that could not be determined) and II (a Venezuelan crude source). The binders were transported to the laboratory in sealed 5 gallon containers to prevent oxidation and premature aging. Table 2 gives the properties of the binder sources. Four different anti-stripping agents were used in the project. They were commercially available hydrated lime, three liquid ASAs denoted as 1, 2 and 3 respectively. The fifth treatment was the Control, no ASAs, denoted by ‘0’ in this paper.

TABLE 2 Binder Properties

Property	Binder I	Binder II
Original Binder		
Viscosity, Pa-s (135˚C)	0.405	0.626
G*/sin δ, kPa (64˚C)	1.207	1.801
RTFO Residue		
Mass Change, % (163˚C)	-0.02	-0.24
G*/sin δ, kPa (64˚C)	2.815	4.608
PAV Residue		
G*/sin δ, kPa (25˚C)	2970	2420
Stiffness (60), MPa (-12˚C)	183	129
m-Value (60) (-12˚C)	0.311	0.345
PG Grade	64 -22	64 -22
Mixing Temperature⁺, ˚C	150 – 155	163 – 170
Compaction Temperature⁺, ˚C	139 - 144	150 – 155

⁺*Information provided by supplier*

In this paper, each of the mixes is given a unique code containing 3 parts. The first part is the aggregate (A, B or C); the second part represents the binder source; (I or II), and the third part for the ASAs; (0, 1, 2, 3 or L). The age of the samples is denoted by the number before the mix code. For example, 180AIIL denotes a 180 day sample prepared by mixing aggregate A with binder II and Hydrated lime as the ASA treatment.

RESULTS AND DISCUSSIONS

The Superpave method of mix design was used to determine the optimum binder contents of various mixtures. Table 3 gives the results of the mix design for the 30 mixes. Knowing the optimum binder content for each of the mix designs, ITS samples were made for each of the mix type. Four samples for each age (e.g., 1 day, 90 days, etc.) were prepared to test the ITS. Two of which were stored as dry samples at 25 ± 1˚C, and two were stored as wet samples. If the samples were to be broken after 1 day, the wet samples were submerged in water at 60 ± 1˚C for 24 hours followed by submersion in water at 25 ± 1˚C for 2 hours before breaking. For conditioning durations of more than 1 day, the wet samples were submerged in a water bath at 25

± 1˚C for one day short of that specific duration (e.g., 6 days, 27 days, etc.) and then they were submerged in a water bath (60 ± 1˚C) for 24 hours followed by submersion in water at 25 ± 1˚C for 2 hours before breaking. All the wet samples were vacuum saturated to a saturation level of 70% to 80% before immersing in water.

The wet ITS and the TSR were used as the measure of stripping for each of the mixes. To study the effects of ASAs and aggregates on the mixes, a Randomized Complete Block Design (RCBD) was developed with the ASAs as the treatment variables and the aggregate source as the block variables. Similarly, a RCBD was developed with the binder source as the block variable to study the effects of the binder sources. Analysis of variance (ANOVA) was then performed to test the null hypothesis which was the mean ITS (or TSR) of each treatment and block variables are not significantly different from each other at the 5% level of significance.

TABLE 3 Mix Design Results

Mix Type	Optimum AC (%)	VMA (%)	VFA (%)	Air Voids (%)
AI0	5.8	17.5	76	4.0
AI1	5.9	17.7	77	3.9
AI2	5.9	17.7	77	3.9
AI3	5.9	17.7	77	3.9
AIL	5.7	16.8	77	3.8
AII0	5.8	17.3	77	3.9
AII1	5.8	17.6	77	3.9
AII2	5.8	17.6	77	3.9
AII3	5.8	17.6	77	3.9
AIIL	5.4	16.2	76	3.4
BI0	4.6	15.1	74	3.4
BI1	4.6	15.2	72	3.7
BI2	4.6	15.2	72	3.7
BI3	4.6	15.2	72	3.7
BIL	4.4	14.5	76	3.5
BII0	4.6	15.0	73	3.4
BII1	4.5	14.8	73	3.5
BII2	4.5	14.8	73	3.5
BII3	4.5	14.8	73	3.5
BIIL	4.4	14.5	73	3.5
CI0	5.8	17.2	76	3.9
CI1	5.8	16.8	77	3.9
CI2	5.8	16.8	77	3.9
CI3	5.8	16.8	77	3.9
CIL	5.2	14.6	76	3.3
CII0	5.8	17.1	76	4.0
CII1	5.7	16.6	77	3.6
CII2	5.7	16.6	77	3.6
CII3	5.7	16.6	77	3.6
CIIL	5.3	15.2	76	3.4

After conditioning the samples for 1 day and 7 days, mixes with hydrated lime gave the highest wet ITS. They were followed by mixes with the liquid ASAs. The control treatment was the least effective. After 28 days of conditioning, no general trend was observed. It was observed that certain aggregate/ASA or binder/ASA or aggregate/binder/ASA combinations work better than others. In general, hydrated lime seemed to be the most effective ASA. For longer durations of conditioning, namely 90 days and 180 days, mixes with hydrated lime and the liquid ASAs were equally effective, and performed better than mixes with no treatment. A similar set of ANOVA tests, at the 5% significance level, were performed on the TSR values of the samples. Based on these results, it was observed that mixes with hydrated lime and the liquid ASAs gave similar TSR values when conditioned in water for durations beyond 1 day. After conditioning the samples for 1 day, mixes with hydrated lime gave the highest TSR values, followed by the liquid ASAs with no significant difference in their effectiveness, then followed by the control treatment.

For mixes prepared with stored binders, there were no significant differences in the ITS values of mixes with different ASA treatments. This was observed at 1 day, 28 days and 90 days of conditioning. The only exception was mixes with binder source II after 90 days of conditioning, where the use of hydrated lime seemed to be effective, statistically, in improving the wet ITS. The TSR values also showed a similar trend, where none of the anti-stripping treatments performed significantly different from the others after 1 day, 28 days and 90 days of conditioning.

Effect of Aggregate Sources

In most cases, it was observed that mixes with aggregate source B gave the highest wet ITS after all conditioning durations. Mixes with aggregate source A and C followed with no significant difference in their mean wet ITS values after all conditioning durations. Figure 3 (a – e) shows the effects of aggregate source on the wet ITS of the mixes at different conditioning durations. As far as the effect of the aggregate source on the TSR of mixes was concerned, there was no significant difference in the values of the mean TSR for mixes with different aggregate sources. This was the case at 1 day as well as at 7 days. However, at 28 days, mixes with aggregate source B showed significantly lower TSR values compared to the other aggregate sources. This may be explained due to the reason that mixes with aggregate source B showed exceptionally higher dry ITS compared to the mixes with other aggregate sources. After longer durations of conditioning (90 and 180 days), there was no significant difference in the TSR values of the mixes with different aggregate sources.

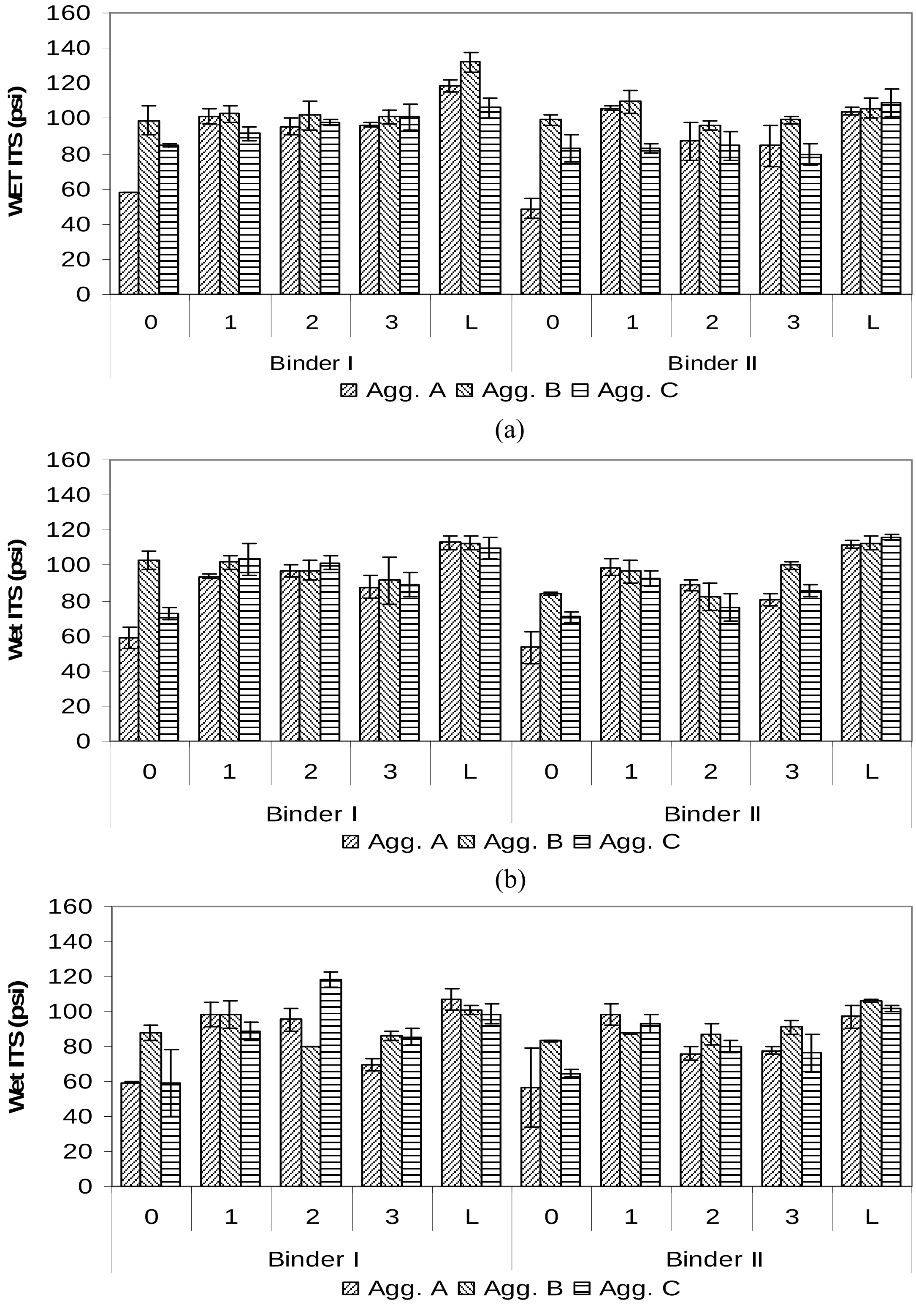
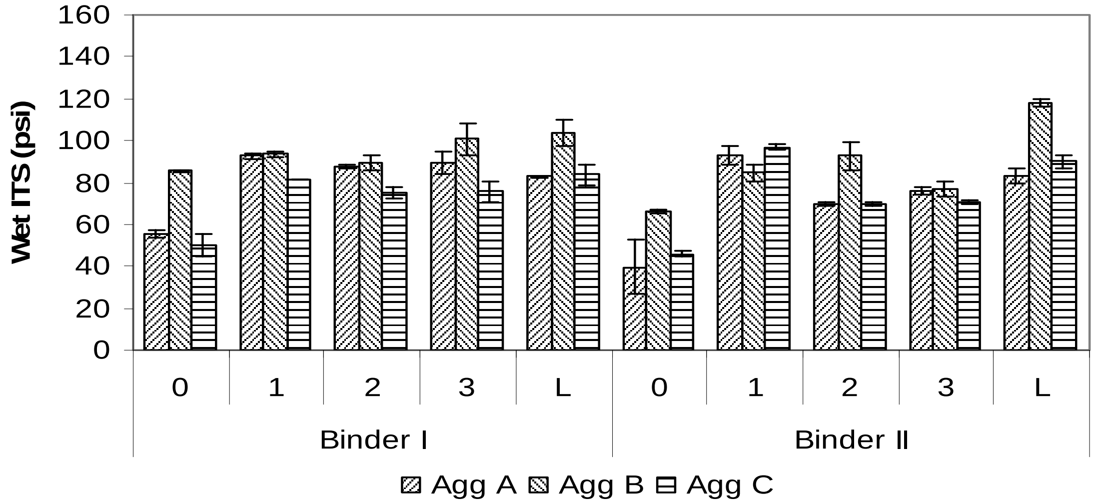
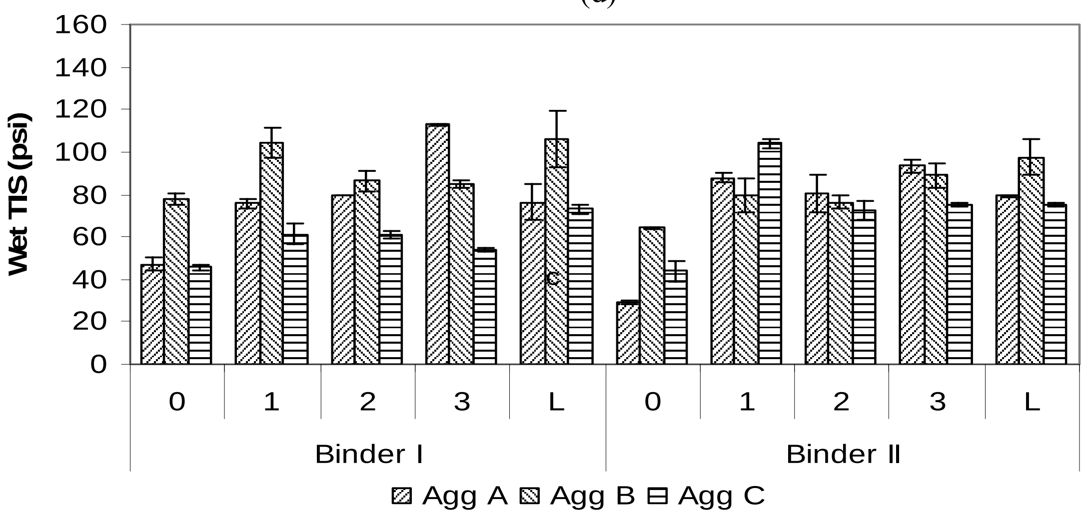


Figure 3 Effects of conditioning duration on wet ITS (a - 1 day conditioning; b - 7 days conditioning; c - 28 days conditioning; d - 90 days conditioning; e - 180 days conditioning).



(d)



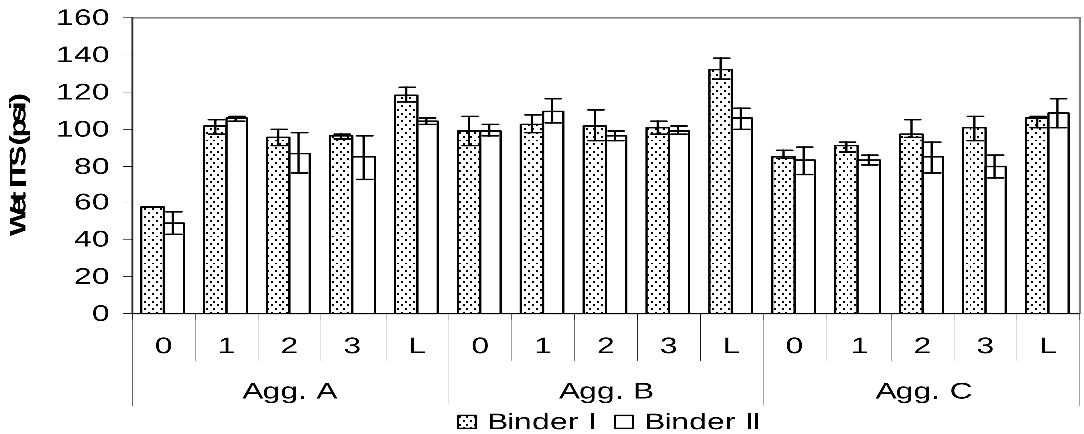
(e)

FIGURE 3 Continued.

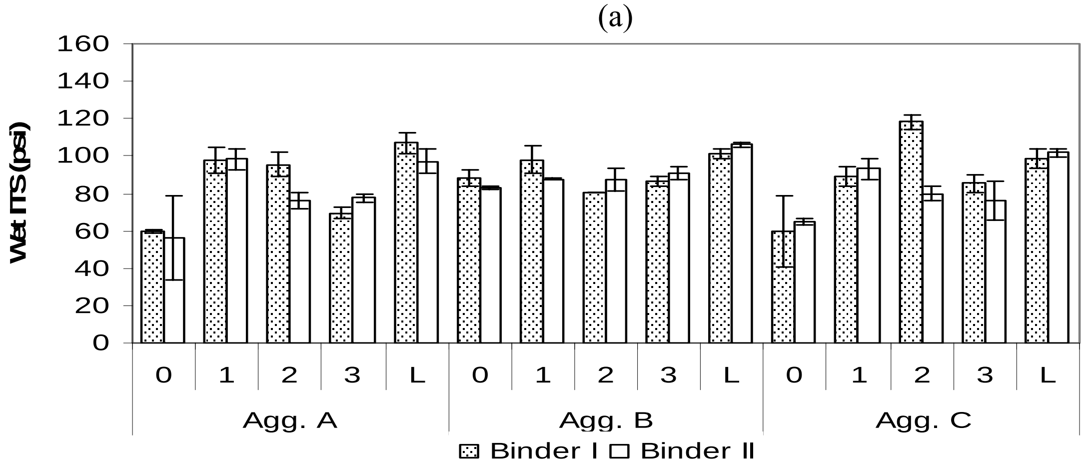
Even when stored binder was used to prepare the samples, mixes with aggregate source B gave the highest wet ITS after 1 day of conditioning. However, after 28 and 90 days of conditioning, the mean wet ITS of mixes with different aggregate sources were significantly similar, at the 5% level. When the TSR values of the mixes were compared after 28 days of conditioning, mixes with aggregate source B gave the highest TSR values.

Effect of Binder Source

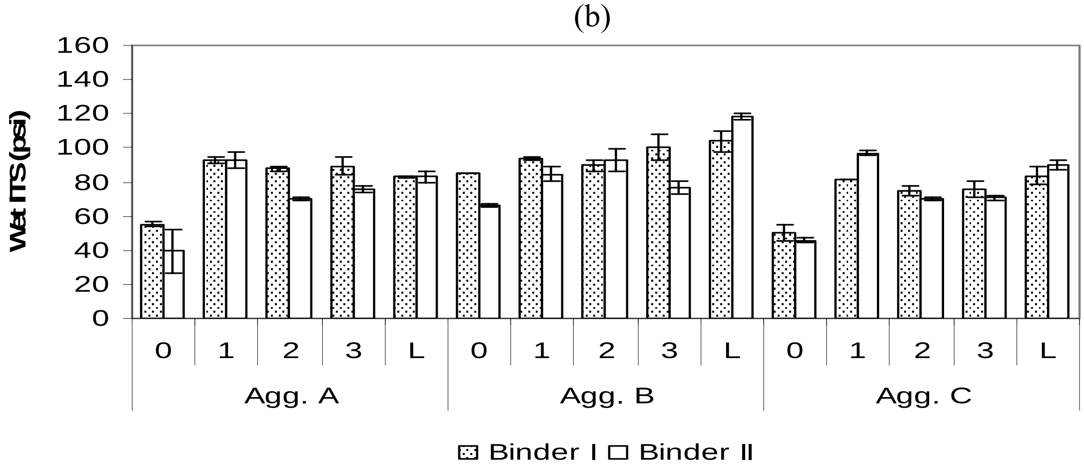
The ANOVA performed to check the effect of binder source on the wet ITS of mixtures showed that the mixes with fresh binder I generally gave higher wet ITS at 1 day, except in the case of mixes with aggregate source B, where the mean strengths of mixes with both binders were not significantly different. After other conditioning durations, there was no significant difference in the mean wet ITS of the mixes with either binder source. Also, the binder source did not seem to have any effect on the TSR values of the mixes used in this research after all conditioning durations. Similar trends were observed when stored binder was used to prepare the samples. None of the binder sources used in the research showed significantly different wet ITS or TSR values. Figures 4 (a – c) and 5 (a – c) show the effects of binder source on the wet ITS and TSR values of the mixes at different conditioning durations.



(a)

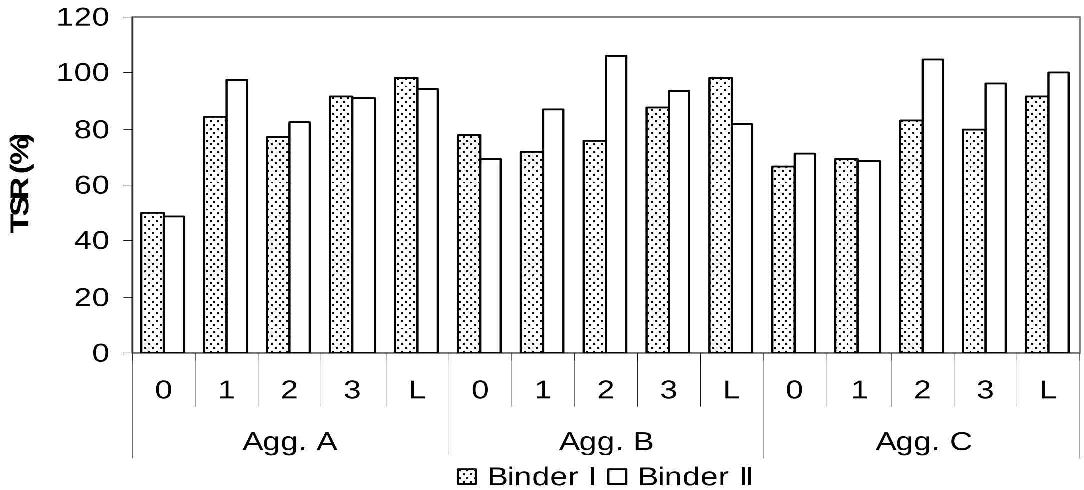


(b)

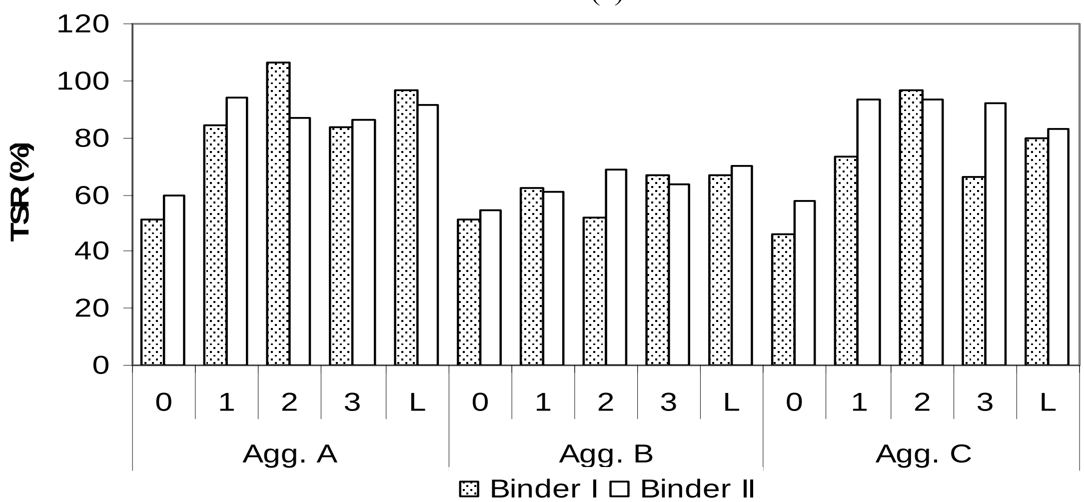


(c)

FIGURE 4 Effects of binder source on wet ITS (a – 1 day conditioning; b – 28 days conditioning; c – 90 days conditioning).



(a)



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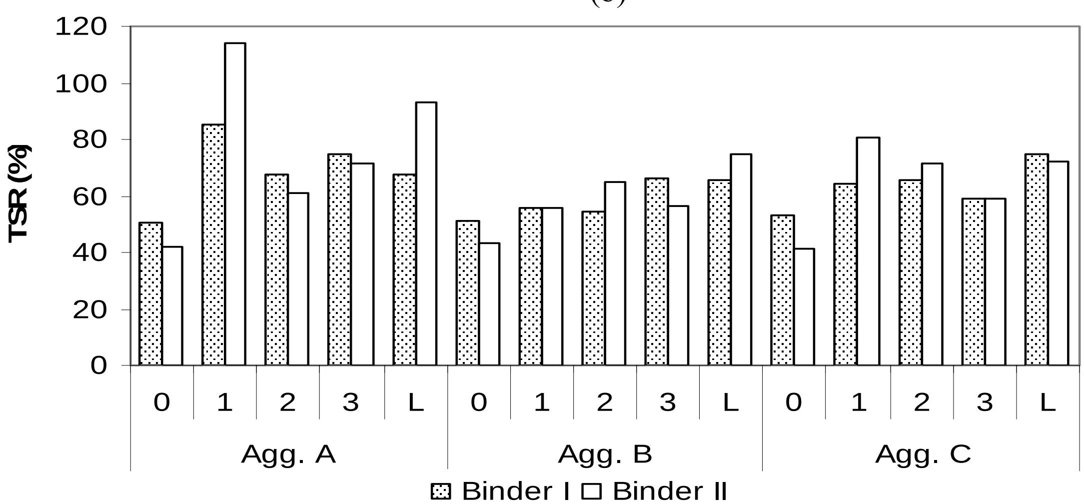
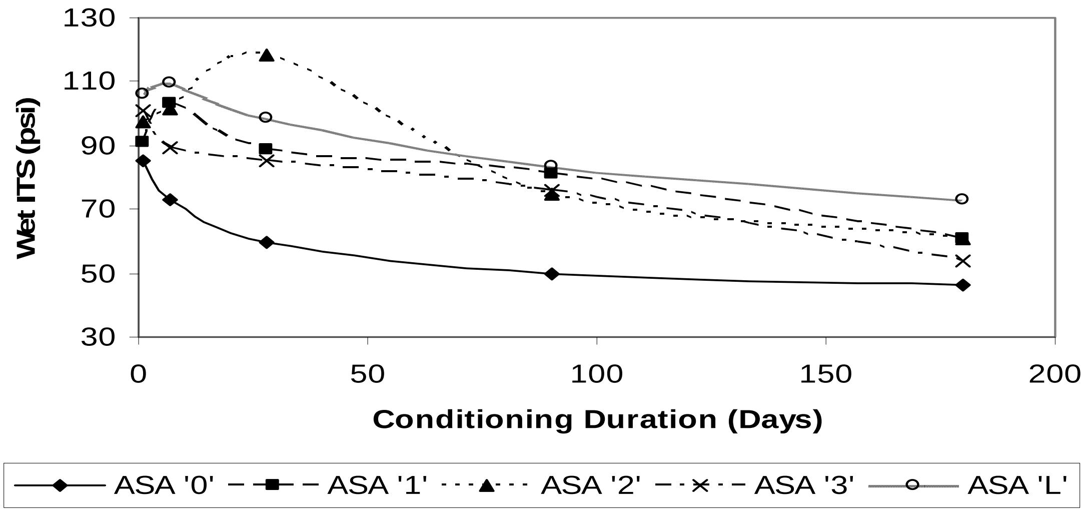


(c)

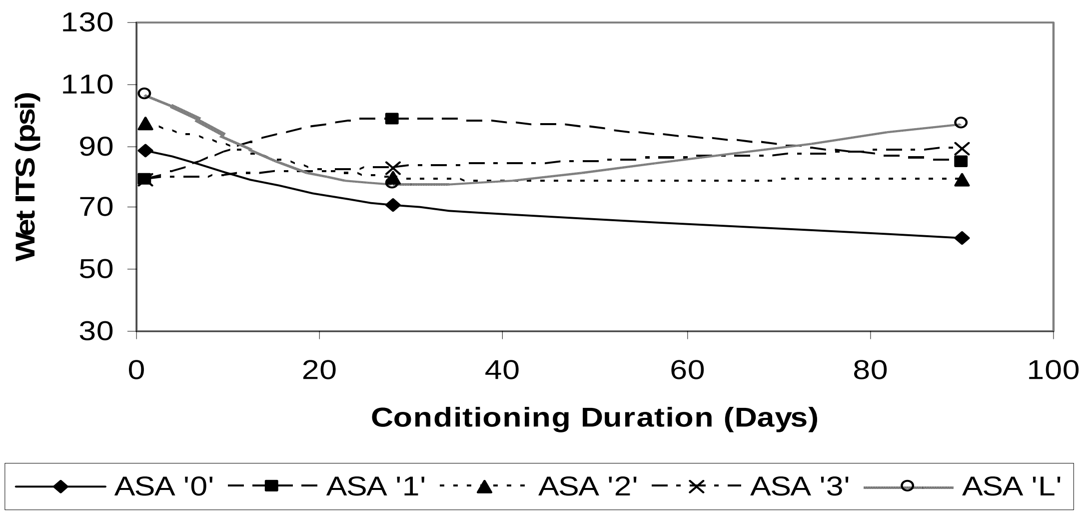
FIGURE 5 Effects of binder source on TSR (a – 1 day conditioning; b – 28 days conditioning; c – 90 days conditioning).

Effect of conditioning duration

To check the effect of moisture on the samples over a long duration of time, the mean wet ITS and the TSR values of the samples were compared for different conditioning durations. The comparison revealed that all mixes prepared from fresh binder yielded significantly higher wet ITS values after shorter durations of conditioning (1 and 7 days) compared to higher durations of conditioning (90 and 180 days). However, most of the mixes prepared from stored binder yielded significantly similar wet ITS values after conditioning for 1, 28 and 90 days. Figures 6 (a – b) and 7 (a – b) show the wet ITS and TSR of mixes with aggregate source C and binder source I. Other mixes also followed similar trends.



(a)



(b)

FIGURE 6 Effects of conditioning durations on wet ITS (aggregate C; a – fresh binder I; b – stored binder I).

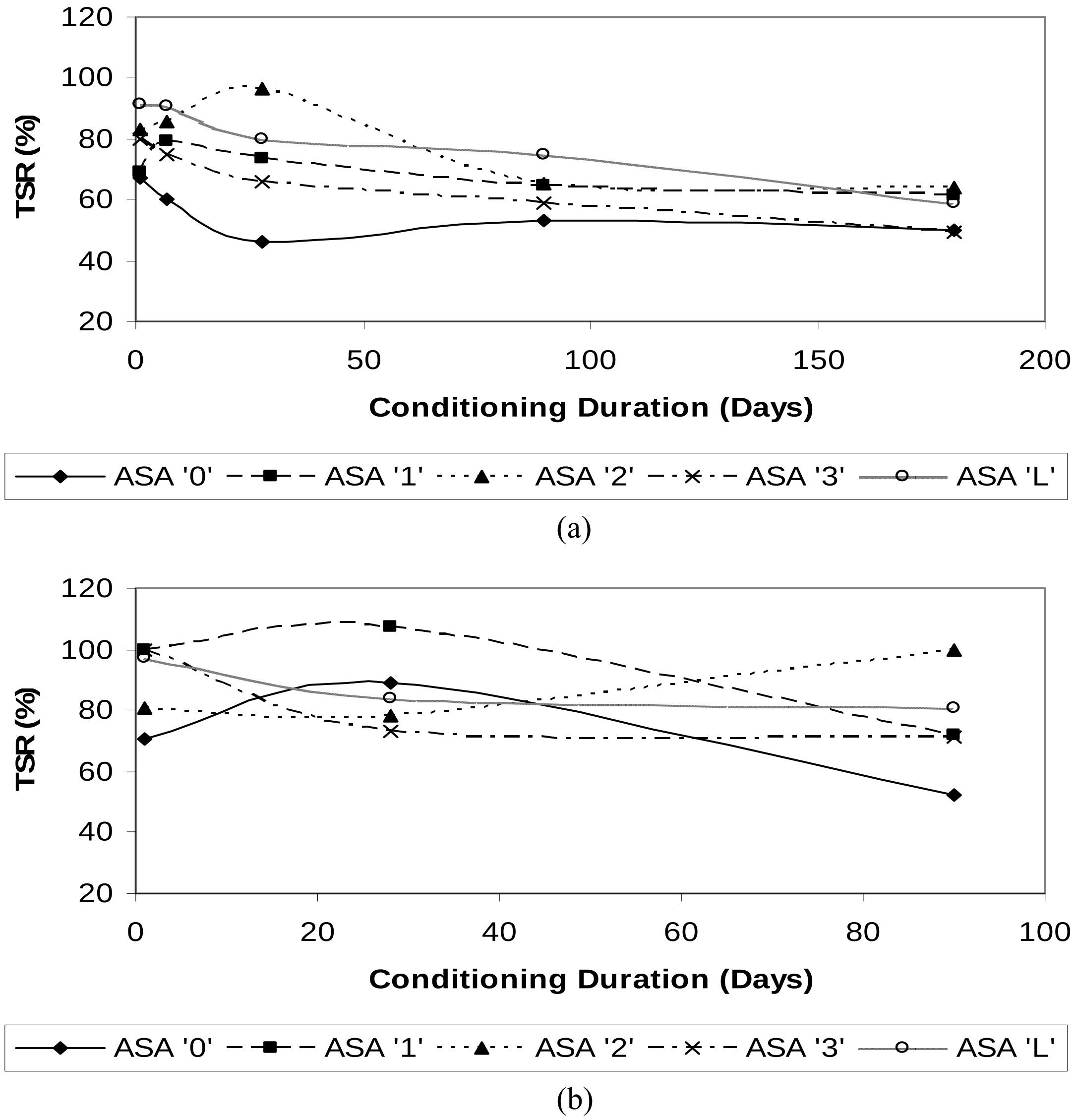


FIGURE 7 Effects of conditioning durations on TSR (aggregate C; a – fresh binder I; b – stored binder I).

In addition, it was observed that all the mixes prepared with stored binders, and with hydrated lime as the ASA, showed significantly similar strengths after 1, 28 and 90 days of conditioning. Whereas, mixes prepared from fresh binder, and with hydrated lime as the ASA, showed significantly higher strengths after 1 and 7 days of conditioning compared to strengths obtained after 90 and 180 days of conditioning.

Comparison of Fresh and Stored Binder Mixes

To determine the heat storage stability of the liquid ASAs, the mean wet ITS and TSR values of samples prepared from fresh binder were compared with that of stored binder after each conditioning duration. A simple 't-test' was used to make this comparison. From the comparison, it was observed that although none of the ASA treatments were significantly better performing when stored binder was used to prepare the samples, almost all the mixes showed significantly similar wet ITS and TSR values when compared to fresh binder. This was observed after 1, 28 and 90 days of conditioning in water. Thus, it could be concluded that the liquid ASAs, used in this research project, do not appear to lose their effectiveness when stored in the oven for 3 days at 163˚C.

SUMMARY AND CONCLUSIONS

This research was conducted to study the effectiveness of liquid ASAs over longer durations of conditioning. Some of the storage stability issues related to the use of liquid ASAs were also investigated. A total of 30 mixtures including three aggregate sources, two binder sources, and five anti-stripping treatments (including control treatment – no ASA) were used in this investigation. ITS samples were prepared and tested after conditioning them in water for 1, 7, 28, 90 and 180 days. To study the storage stability issue, samples were prepared from binders stored for 3 days at 163˚C and then tested after conditioning in water for 1, 28 and 90 days.

From the study conducted, the following could be concluded.

- After one and seven days of conditioning in water, hydrated lime seemed to be the most effective ASA treatment. Hydrated lime was followed by the three liquid ASAs, which were followed by the control treatment (no ASA). However, after longer durations of conditioning (90 and 180 days) none of the ASA treatments were significantly different from the others.
- When stored binders were used to prepare the samples, none of the ASA treatments showed any significant improvement in the wet ITS or the TSR values of the mixes. Thus, it could be concluded that none of the ASA treatments used in this research were effective after longer durations of conditioning.
- Although aggregate source B showed higher ITS values after conditioning for 1 and 7 days, its TSR values were similar to mixes with other aggregate sources. Also, after higher conditioning durations, the wet ITS and TSR values of mixes with all aggregate sources were significantly similar. Thus, it can be concluded that the aggregate sources used in this research work had no significant effect on the effectiveness of the ASA treatments.
- Similar to the aggregate source, the binder source also did not seem to have any significant effect on the effectiveness of the ASA treatments. None of the binder sources showed significantly higher wet ITS or TSR values compared to others.
- Certain aggregate/binder combinations yielded higher wet ITS and TSR values compared to others. It could be hypothesized that each aggregate/binder combination is unique, and that each combination has to be individually examined for moisture susceptibility. It should be noted that the liquid ASAs added were 0.5% by weight of binder. This was based on the 0.25% - 0.75% recommended by the suppliers. Thus, if more liquid ASA was added to the aggregate/binder combinations that did not work, different results could have been obtained.

- For mixes prepared from fresh binder, the conditioning duration has a significant influence. The wet ITS and the TSR values of the mixes reduced significantly after longer conditioning durations. However, for mixes prepared from stored binders, the conditioning durations did not have any significant influence. The wet ITS and the TSR values were significantly similar after 1, 28 and 90 days of conditioning.
- Since the wet ITS and the TSR values of the samples prepared from stored binders were significantly similar to the wet ITS and TSR values of the samples prepared from fresh binder, it is concluded that the liquid ASAs used in this study do not break down under the heat when stored for 3 days at 163˚C.

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