Analysis of Moisture Susceptibility of Different Loose Coated Asphalt Mixtures

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Abstract-The durability is one of the significant properties of bituminous paving mixtures. It is shown that moisture damage is one of the primary factors affecting the durability of the mixtures. Moisture damage is basically a combined result of two mechanisms: a) Loss of adhesion between the bitumen and aggregate interface and b) Loss of cohesion in the mixture along with several other factors like the changes in binders, aggregates qualities and something else.

The aim of this study is therefore to examine the moisture sensitivity, of different combinations of five different kinds of aggregate quarries/sources and six binder types of different penetration grade and properties, and compare the performance of these combinations between four laboratory tests: Static Immersion Test, Total Water Immersion Test (TWIT) Test, Boiling TWIT Test and Rolling Bottle Test. The tests have been carried out at the Taxila Institute of Transportation Engineering (TITE) to obtain the data for loose coated bituminous paving mixtures. The results show that the combination of Margallah aggregate source and ELVALOY Polymer Modified Bitumen provides best resistance against moisture damage and Rolling Bottle Test is the best test to discriminate between different loose coated Asphalt mixtures, irrespective of time taken by the test.

Keywords-Moisture Sensitivity Tests, ELVALOY, Polymer Modified Binder, Rolling Bottle Test, Margallah.

I. INTRODUCTION

WATER is majorly influencing the physical and mechanical properties of bituminous paving mixtures in our country. In fact, moisture damage in asphalt pavements is a global concern. Moisture damage in an asphalt mixture is defined as the loss of strength, stiffness and durability due to the presence of moisture leading to adhesive failure at the binder-aggregate interface and/or cohesive failure within the binder or binder-filler mastic. [i] Moisture damage such as stripping, rutting, raveling and fatigue cracking contributes significantly to the failure in bituminous paving mixtures. Factors are various and there are still no satisfying solutions for this problem. There are two major factors that caused moisture-related problems: adhesive failure, bitumen stripping off the aggregate surface and cohesive failure which is due to the loss of mixture stiffness. Moisture-related problems do not occur without the presence of water and traffic, which provides energy to break the adhesive bonds and cause cohesive failures. Repeated freeze-thaw cycles can also accelerate the distress in the pavement.

Since the performance of Asphalt mixtures under the affect of moisture is a very complex issue, various researches have been made to simulate the moisture damage in the past years. Asphalt technologists have carried out many attempts to develop laboratory tests to distinguish between good and poor performing bituminous mixes in regard to moisture damage dating back to the 1920s and classified the tests to identify the moisture damage resistance of an asphalt mixture into two major categories: those on loose mixtures and those on compacted mixtures. [ii]

II. PROBLEM STATEMENT

Adhesion and water proofing characteristics of bitumen made it a widely used binder in roadway pavements. However, structural and functional integrity of bituminous paving mixtures, due to loss of adhesion between bitumen and aggregate surfaces and loss of cohesion of asphalt, can be easily damaged under moisture conditions. Both mechanisms generally result in a reduction of strength and/or stiffness of the mixture and, thus, its effectiveness to accommodate traffic-induced stresses and strains. Consequently, the water-damaged pavement layer is prone to stripping i.e. physical separation of the bitumen from the aggregate and permanent deformations. Thus, water damage can also lead to early failure. Therefore it is necessary to find out how to avoid water damage. Generally speaking, adhesion between bitumen and aggregate depends on the balance of bitumen, aggregate and water system.

III. AIMS AND OBJECTIVES

The aim of this study is to examine the affinity between aggregates and binders in loose coated asphalt mixtures of various combinations by varying aggregate

quarries and grades and properties of binder, by means of additives and modifiers, and compare the performance between these different combinations using following four tests: Static Immersion Test, Boiling TWIT Test, Rolling Bottle Test, TWIT Test. In order to achieve this aim, a few series of water sensitivity tests on loose coated asphalt mixtures were carried out.

IV. Literature Review

Mechanics of the bonding of aggregate-binder interface, which is highly affected due to moisture conditions, influences the response of bituminous mixtures towards different distresses. Basically following three mechanisms result in moisture degradation of an asphalt mixture i.e. a) Loss of cohesion within binder, b) Adhesion failure between binder and aggregate interface (i.e. Stripping) and c) Degradation of aggregate. In evaluation of binder's resistance against moisture damage, the critical parameter is bond strength, which is between asphalt and aggregate interface. [iii] K. Majidzadeh and F. N. Brovold [iv] carried out study to alleviate deformations or to control the rate of deteriorations in pavements, caused by the moisture damage, resulted in utilization of anti-stripping additives. The physico-chemical bond between the bitumen and aggregate in a bituminous mixture can be increased by using anti-stripping additives. These anti-stripping additives can also be used to improve the wetting of asphalt over aggregate surface by lowering the surface tension of the bitumen. The affect of hydrated lime on the mechanism that affects the adhesive bond between bitumen and aggregate in a bituminous mixture is evaluated again in 2013 [v], but this time, by using surface free energy method. The results of this surface free energy method indicated that hydrated lime increases the wettability of asphalt binder over the aggregate and improves the adhesion between the asphalt binder and aggregate. Also, the difference between surface free energies of asphalt-aggregate and water-aggregate is higher in samples made with untreated aggregates, as using hydrated lime caused these values to decrease. This implies that more energy is needed for stripping phenomena to occur, and the rate of moisture damage decreases .

In 1990, K. D. Stuart [vi] practiced following five anti-stripping additives in the laboratory (a) traditional liquid additives, (b) metal ion surfactants, (c) hydrated lime and quick lime, (d) silane coupling agents and (e) silicone. Among these five additives the most commonly used and effective solid type anti-stripping agents are Hydrated and quick lime. In 2009, C. Gorkem and B. Sengoz [vii] studied the affect of hydrated lime on the stripping potential and moisture susceptibility characteristics of hot mix asphalt (HMA). The results of which showed that the addition of hydrated lime in hot mix asphalt (HMA) increased the resistance of asphalt mixtures to the detrimental effect of moisture. Sobolev et al. [viii] studied the addition of Fly ash in asphalt pavements for the improvements in performance of asphalt binders as compared to those improvements which are achieved through polymer modification.

In 1960's and 1970's, many attempts were made by researchers for the modification of existing test procedures, for determining moisture sensitivity of asphalt mixtures, and simulation of these methods with actual field conditions. These attempts resulted in a very effective moisture sensitivity test development when Lottman's test protocol was introduced in industry. This achievement is considered as breakthrough in the history of moisture sensitivity tests development and standardized under the AASHTO test procedures specifications T283. Texas freezethaw pedestal test and Texas boiling test were also introduced to industry at that time [ix].

V. Methodology

Four tests were performed to carry out the study of moisture susceptibility of loose coated asphalt mixture comprises of different grades and different properties of asphalt binders (by application of additives and modifiers) i.e. Static Immersion Test, Total Water Immersion Test, Boiling Water Test and Rolling Bottle Test. The commonly used grades are 10/20, 60/70 and 80/100, the binders with additives are Lime additive 60/70pen binder and Fly Ash additive 60/70pen binder, and Polymer Modified Binder (PMB) comprises of ELVALOY (DuPont reactive ethylene tarpolymer).

TABLE I
Mean Penetration Values of Selected Binders

Sr. No	Binder Type	Mean Penetration Value(mm)
1	10/20 pen	14
2	60/70 pen	61
3	80/100 pen	84
4	Lime Additive 60/70 pen	53
5	Fly Ash Additive 60/70 pen	26
6	Polymer Modified Binder	24

The aggregates from Rohi, Ubban Shah, Margallah, Sargodha and Garrhi Habib Ullah were used in these combinations along with binders mentioned above. The results so obtained are compared between moisture resistant properties for, different grades, additives and modifiers of different binders, aggregate properties and four moisture sensitivity tests mentioned earlier.

The methodology adapted for this work is shown in Fig. 1.

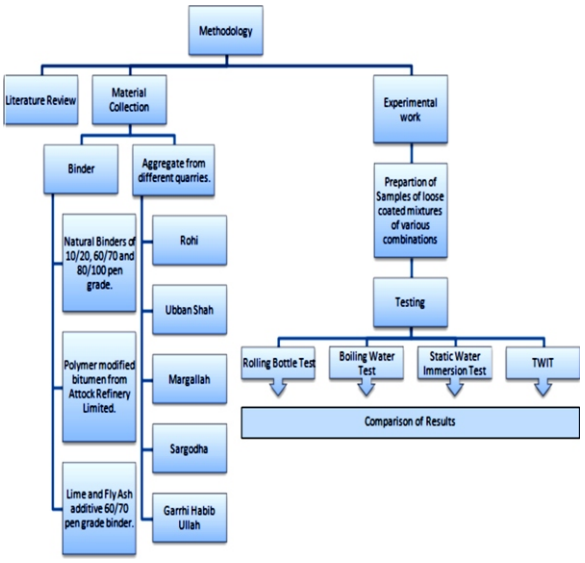

Fig. 1. Research Methodology

VI. Results and Discussion

A. Static Immersion Test

The observation of this test is only to estimate the percentage of the total visible area of the aggregate which remains coated as above or below 95 percent. It was found that the stripping of the binder is not very obvious, and what is more, most of the results are nearly 100% remained. The results are plotted on Fig. 2.

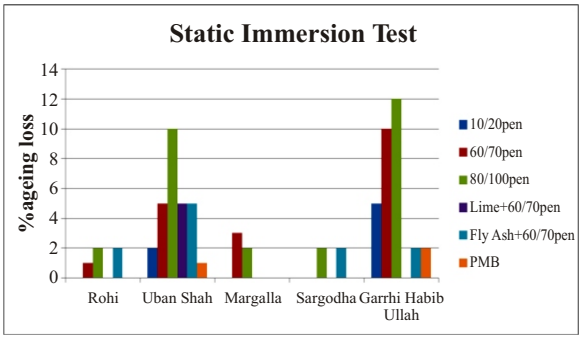

Fig. 2. Results for Static Immersion Test

From the bar chart, we can see that most combinations show good bonding properties except for the combinations of Garrhi Habib Ullah and Ubban Shah with 80/100pen binder and also of Garrhi Habib Ullah with 60/70pen binder, which are 12% and 10% stripping of binder, respectively. The combination of Ubban Shah with 60/70pen simple and along with Lime and Fly Ash as additives and Garrhi Habib Ullah along with Fly Ash additive binder also lost 5% of binder.

B. Rolling Bottle Test

In the Rolling Bottle Method, the degree of bitumen coverage of the particles is checked after 6 hours, 24 hours, 48 hours, and 72 hours. The bar chart below shows the total loss of bitumen after 72 hours.

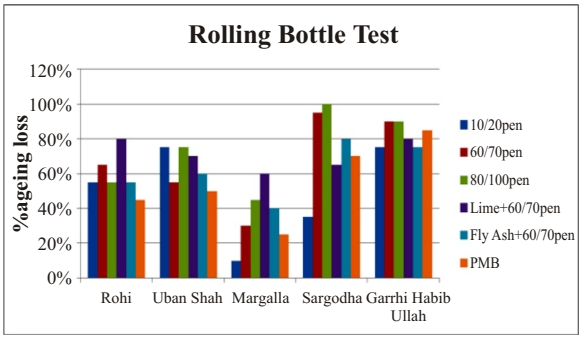

Fig. 3. Percentage loss of Bitumen after 72 hours of Rolling Bottle Method

It can be seen from the bar chart clearly that 80/100pen, 60/70pen and Lime additive 60/70pen binder had the highest binder lost after 72 hours. The loss of Fly Ash additive 60/70pen binder, however, is just slightly less than above mentioned binders. However, Polymer modified binder shows very better bonding properties. In terms of aggregate, Margallah performs better than other sources. To be specific Garrhi Habib Ullah has the worst bonding properties, followed by Ubban Shah and Sargodha, while Margllah is the best which is only about 25-30% average binder loss. As far as the comparison of 6 and 24 hours of 60/70pen binder with Lime additive 60/70pen binder is concerned, a very distinct and clear decrease in percentage of binder loss is observed.

C. Total Water Immersion Test

TWIT assesses the average percentage of binder coverage after immersion in 40°C water after 3 hours. This test is improved from Static Immersion Test. It uses 40°C water rather than room temperature (25°C) to provide a better result. As present before, the results of Static Immersion Test are not obvious; however, Figure below shows the results of Total Water Immersion Test which are comparatively clearer. From the bar chart we can see that Rohi and Margallah have very little binder loss compared with Ubban Shah and Garrhi Habib Ullah. The percentages of binder loss for these two are all less than 5% for the three binder types. When it comes to Ubban Shah and Garrhi Habib Ullah, the percentages of binder loss are quite higher. However, Sargodha shows nearly the same bonding properties with Margallah which are only 4% for Lime additive 60/70pen binder and no binder loss for 10/20pen and Polymer Modified binder. Ubban Shah is again the worst aggregate with 25 to 30% binder loss, followed by Garrhi Habib Ullah, which have 10% and 25% binder loss. 10/20pen and Polymer Modified

binder have very good bonding properties when compared with other binders.

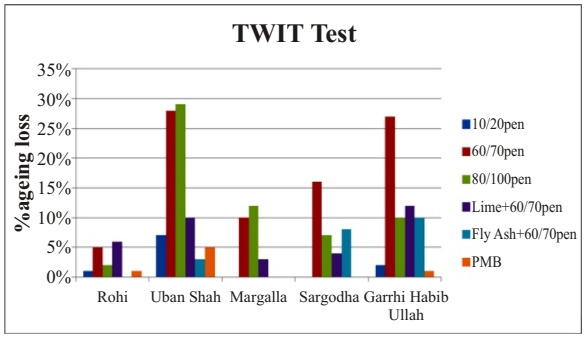

Fig. 4. Results of TWIT

D. Boiling Water Test

The Boiling Water Test estimates the percentage of bitumen coverage after 10mins boiling. The results are very obvious.

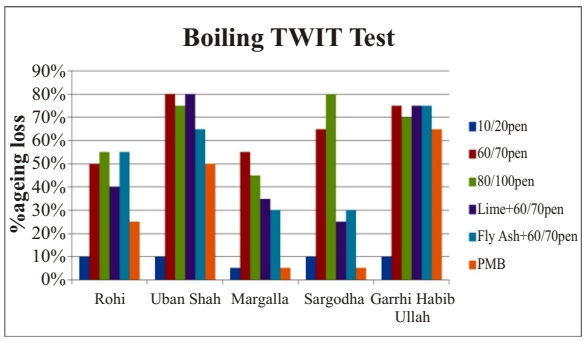

Fig.5. Results of Boiling Water Test

Fig. 5 shows the percentage of binder loss for Boiling Water Test. From the bar chart, we can see that Ubban Shah and Garrhi Habib Ullah, again, have the worst bonding property. As for Margallah and Sargodha, the bond property with Lime additive 60/70pen binder is almost equal (Margallah and Sargodha) or better (Sargodha) than that with Fly Ash additive 60/70pen binder. In terms of Ubban Shah, Margallah and Garrhi Habib Ullah, 80/100pen binder seems to have a better bond property than 60/70pen binder except for Rohi and Sargodha which has 5-15% more binder loss. Since 80/100pen is softer than 60/70pen binder, the bonding property of it should be worse. However this result is different from the expected outcome. The reason why this happened may because that 80/100pen has a lower softening point and when boiling the sample the 80/100pen binder began to flow like large pieces around the aggregate particles and when boiling stopped , the binder start to subside on the aggregate surface. Moreover there is half an hour cooling time, many binder pieces may subside on the particles. More tests should be done to support this supposition. Bar chart also shows that the bonding behavior of PMB is far better than other binders against boiling also. However, in case of Margallah and Sargodha aggregate sources coated with PMB, only 5% binder loss is observed.

VII. Results Analysis

A. Aggregate Source

The results indicate that Margallah has a better bonding property followed by Rohi. Generally speaking, hydrophobic aggregates are less sensitive to moisture, i.e. are more resistant against stripping, than hydrophilic aggregates. As hydrophobic aggregates forms a better bond therefore it is hard for water to access to the surface of aggregates. Hence it can form bonds with the bitumen film more easily leading to less possibility of stripping. Iron, magnesium, calcium and perhaps aluminum are considered beneficial, while sodium and potassium are considered detrimental. Limestone, i.e. Margallah and Rohi, is defined as a rock of sedimentary origin composed principally of calcium carbonate or the double carbonate of calcium and magnesium, or a combination of these two minerals. Therefore it should have a better bonding property which is proved by the results.

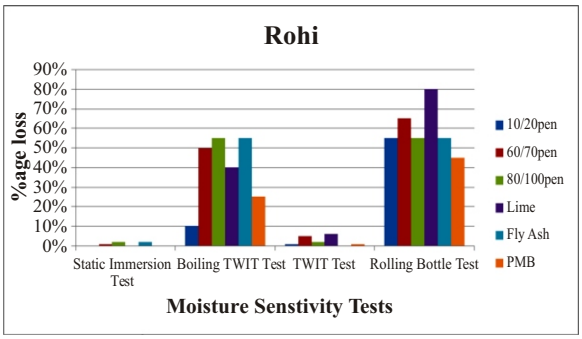

Fig. 6. Moisture Sensitivity Test Results for Rohi

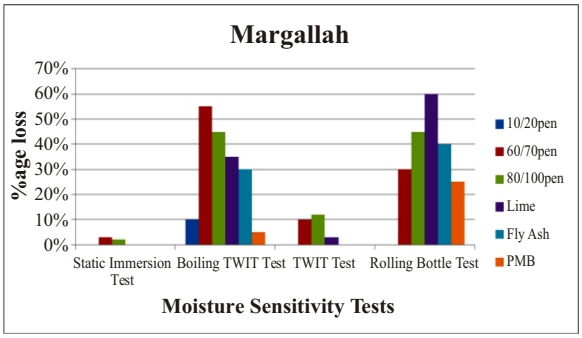

Fig. 7. Moisture Sensitivity Test Results for Margallah

Both the two types of Margallah source i.e. Rohi and Margallah crush have quite low water sensitivity. Mostly results are less than and up to 50-55% of binder loss. The Static Immersion Test and Total Water Immersion Test are not suitable to distinguish the

difference between these two aggregates. There are some minor differences in TWIT which can make a distinction between these two aggregate quarries. Boiling TWIT and Rolling Bottle Test can provide a better reference in related to their bonding properties. Based on the results Margallah have the best bonding properties in both 10/20 pen and Polymer Modified binder types, while Margallah bonds well also with Fly Ash additive 60/70pen binder. Rohi has showed more water sensitivity to the Lime additive 60/70 pen binder and virgin 60/70, 80/100 binder types and same in the case of aggregates from Margallah quarry.

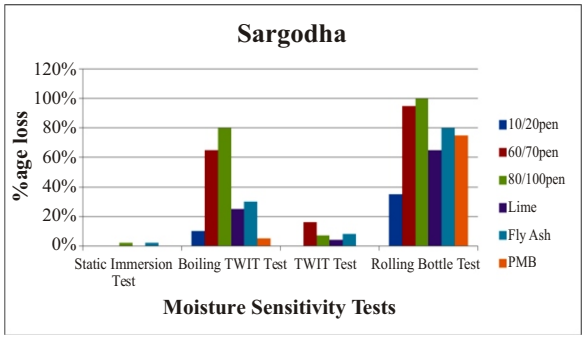

Fig. 8. Moisture Sensitivity Test Results for Sargodha

Aggregates from Sargodha quarry indicated relatively better results. Again Static Water Immersion Test and Total Water Immersion test have not shown clear results whereas other two showed the percentage loss of binder very clearly. Sargodha has shown less binder loss with the binders having additives and modifications as compared to the virgin binders. Results indicate better bonding of Sargodha aggregates with Polymer Modified Bitumen followed by the Lime additive Binder

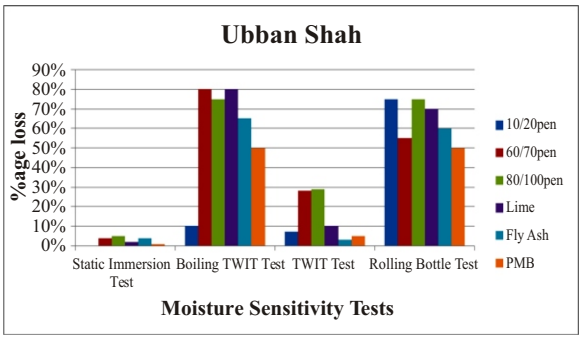

Fig. 9. Moisture Sensitivity Test Results for Ubban Shah

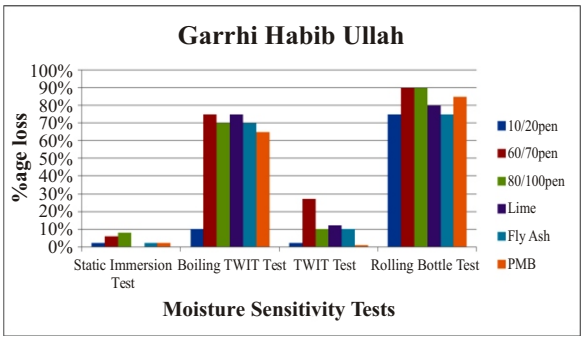

Fig. 10. Moisture Sensitivity Test Results for Garrhi Habib Ullah

Remaining two types of aggregates i.e. Ubban Shah and Garrhi Habib Ullah have very high moisture sensitivity. The percentages of binder loss are all very high especially with the Rolling Bottle Test and Boiling TWIT Test. Almost all the tests can be used to distinguish the difference between these two, Ubban Shah and Garrhi Habib Ullah, aggregate sources. Boiling TWIT Test and Rolling Bottle Test (regardless the testing time) are the best tests to make a distinction between them. TWIT Test can also provide a very reasonable reference to distinguish these aggregate types. In addition, Static Immersion Test is also slightly suitable this time.

Based on the results shown above, both Ubban Shah and Garrhi Habib Ullah aggregate sources have better bonding properties with both 10/20pen and Polymer Modified binder types which is relatively slight weaker than limestone based Margallah and Rohi aggregates, and has the reasonable water sensitivity to the binder type. The sensitivity to the 60/70 binder type is quite strange for Ubban Shah and Garrhi Habib Ullah, however in general, soften binder has a weak bonding property, but in these two cases 80/100pen binder bonds well than 60/70pen Binder in Boiling TWIT Test. The reason for this may because the droplets of binder subside on the aggregate surface with no adhesion or cohesion and this percentage of binder coverage is also counted. Above all, Garrhi Habib Ullah is the worst aggregate type with very high moisture sensitivity, followed by Ubban Shah.

B. Effect of Binder

Adhesive forces between bitumen and aggregate in asphalt mixtures are directly affected by the consistency of bitumen, sensitivity for temperature and other indicators and thus the strength of asphalt pavement and asphalt pavement performance is affected. The higher viscous asphalt has better resistance against moisture than the lower viscous asphalt due to the more polar substances and good wet-ability. 10/20, 60/70 and 80/100pen binder are normal natural Virgin binders and Lime and Fly Ash additive binder made by 60/70pen binder (35% by weight of binder). The Polymer Modified binder is modified

from 60/70pen binder by adding ELVALOY (DuPont reactive ethylene tar polymer).

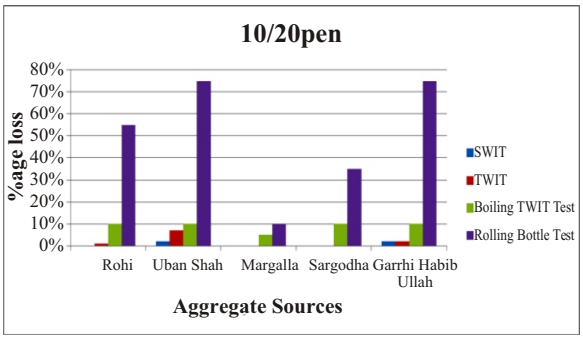

Fig. 11. Moisture Sensitivity Test Results for 10/20 pen Binder

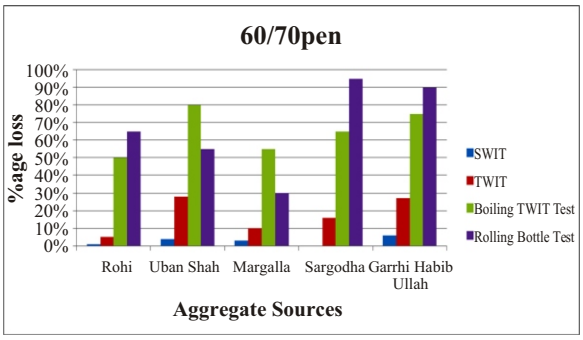

Fig. 12. Moisture Sensitivity Test Results for 60/70 pen Binder

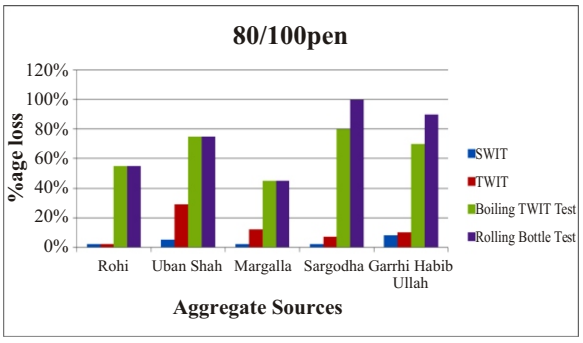

Fig. 12. Moisture Sensitivity Test Results for 80/100 pen Binder

Generally speaking, higher the viscosity of binder higher will be the resistance against moisture damage therefore, the 10/20pen binder is far better and has shown very less percentage loss of binder over aggregate surface. From remaining types of binder, 60/70pen binder is better than 80/100pen binder, because it is stiffer and the penetration of it is much smaller than 80/100pen binder and the softening point is higher. However, the percentage of binder loss of all aggregate types is still comparatively very high, which is hardly acceptable in the field. Therefore anti-stripping additive should be used if the virgin binder needs to be used in the field. The anti-stripping additives (Lime and Fly Ash) and the Polymer Modified binder are therefore tested.

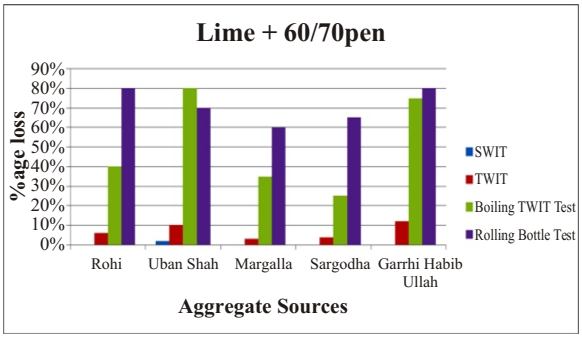

Fig. 13. Moisture Sensitivity Test Results for Lime Additive 60/70 pen Binder

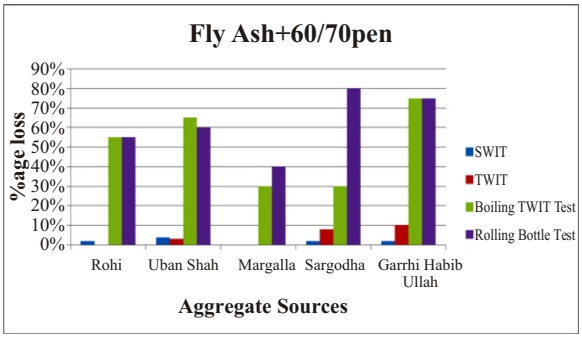

Fig. 14. Moisture Sensitivity Test Results for Fly Ash Additive 60/70 pen Binder

Lime and Fly ash are well known and widely used anti-stripping agents. Most anti-stripping agents reduce surface tension between the bitumen and aggregate in a mixture. When surface tension is reduced, increased adhesion of the bitumen to the aggregate is promoted. Thus, most liquid anti-stripping agents are surface-active agents.

From the bar charts above, we can see that the total percentage of binder loss using Fly Ash additive binder is reduced when compared with Lime additive 60/70pen binder for both Margallah (40%) and Rohi (55%). The better anti-stripping additive for Margallah is Fly Ash with only 30% binder lost as compared to Lime with only 5% better than natural 60/70pen binder. For Sargodha, Ubban Shah and Garrhi Habib Ullah both the Lime and Fly Ash additive binder have shown almost equal percentages of binder loss.

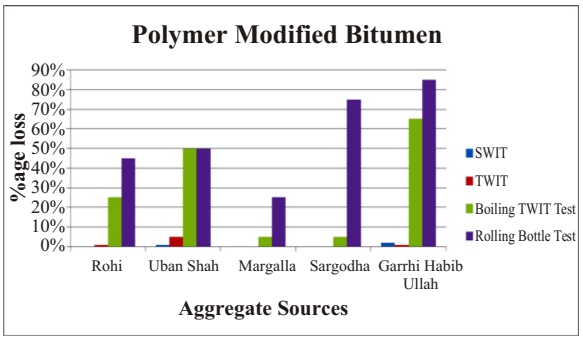

Fig. 15. Moisture Sensitivity Test Results for Polymer Modified Binder

Modification techniques highly affect the performance of asphalt mixtures and are more desirable as compared to the mixtures which are modified with anti-stripping additives. Therefore, Polymer Modified Bitumen should have better bonding properties as compared to Anti-stripping additive binders, which is shown in the results. From the bar charts, we can see that the total percentage loss of binder from the aggregate surface is decreased dramatically by using PMB especially in case of Margallah and Rohi which showed only 25% and 45% binder loss respectively in Rolling Bottle Test where as in Boiling TWIT Test, the percentage of binder loss is reduced to just 5% with Margallah. The worst results of PMB are with Garrhi Habib Ullah aggregate source with up to 85% binder loss followed by the Sargodha aggregates with 75% binder loss in Rolling Bottle Test. Ubban shah also shows almost 50% binder loss with Polymer Modified Bitumen.

One thing must be noticed here that the Boiling TWIT Test showed relatively less percentage of binder loss in case of Polymer Modified Bitumen with all types of aggregate source, which means that ELVALOY (DuPont reactive ethylene tarpolymer) has more resistance against heating affect. It showed only 5% loss with Margallah and Sargodha. As a whole, Polymer Modified Bitumen showed good bonding with almost all types of aggregates regardless of test type.

VIII. Conclusions

Regardless of testing time, Rolling Bottle Test is the most reasonable and acceptable test to evaluate the moisture sensitivity. Meanwhile, Boiling Water Test is the most effective test with the least testing time. TWIT can make a distinction between Limestone based Margallah & Rohi, and others that are Sargodha & Ubban Shah. But as for Static Immersion Test, it is only suitable for Ubban Shah and Garrhi Habib Ullah mixtures, which have very poor bonding properties.

The aggregate characteristics do affect the moisture sensitivity to some extent, irrespective of which type or grade of bitumen is used. The results indicate that Margallah and Rohi have better moisture resistance than remaining types of aggregates. To be specific, Margallah presents the best bonding property while Ubban Shah and Garrhi Habib Ullah show the worst bonding property. That means aggregates containing alkali metals like sodium and potassium exhibit relatively high moisture sensitivity, while aggregates containing calcium, magnesium and iron show little indications of moisture sensitivity. Consequently decreasing the contents of alkali metals in aggregate is a contributor to prevent moisture damage.

Polymers and additives can improve the adhesion between binder and aggregate significantly. To be specific, Polymer Modified binder is the best among all the binders by improving the total percentage of binder loss of Ubban Shah for Boiling TWIT from 80% to 50% and of Margallah from 55% to only 5%. Apart from Polymer Modified Binder, even though Fly Ash additive binder is not polymer based modified binder, it is the better modified binder for Margallah by improving the total percentage of binder loss from 55% to 30%. On the contrary, Garrhi Habib Ullah is only 15% better than the results obtained with virgin binder.

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