An Investigation of the Effect of Anti-Stripping Additives in Hot Asphalt Mixtures

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Abstract: One of the indicators of progress in each country is the development of roadways. Therefore, the importance of constructing roads as well as maintaining them based on heavy costs of construction is very high. In Iran, most of the constructed roads have asphalt concrete treatments. Asphalt concrete consists of two main parts of bitumen and rock materials, and if each of these components does not have the necessary properties, the effectiveness of the pavement will be reduced and have less useful life too. In such cases, the use of additives can improve the properties of asphalt mixtures. Hydrated lime was used as one of the most important additives in asphalt mixtures for the first time in order to prevent the phenomenon of stripping in aggregates of asphalt mixtures. After observing its significant effects in asphalt pavements, serious researches in this field began and its effects on other failure factors of asphalt were investigated. In this research, effects of two main additives - hydrated lime and Zycosil - were investigated with different percentages on the moisture sensitivity of hot asphalt mixtures. The experiments included bulk density, free space percentage, Marshall resistance and indirect pull resistance. Results indicate improved Marshall strength and moisture sensitivity of the mixtures due to the presence of these two additives.

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1. Introduction

Roads are the first and most natural means of human communication, which, as the vital arteries of a land, play a vital role in the development and advancement of societies. Pavement is considered as one of the important components of road infrastructure and should be special and appropriate in terms of the importance of the route in country's road transport network. Therefore, the efforts of researchers and engineers have always been to increase the quality and durability of asphalt mixtures, preventing early damage to the pavement, and postpone these failures as much as possible. Researchers in their studies use special methods by making changes in bitumen, using additives like polymers and altering the structure of asphalt segments to achieve their goals.

Loss of adhesion and cohesion as two main phenomena would cause stripping. The loss of adhesion as a complete detachment of a thin membrane of bitumen took place on rocky materials, in which case, rocky materials without a cover of bitumen and stripped will be observed in the mixture. Cohesion loss is observed as the softening of the bituminous binder, with the penetration of water into the bitumen, and the creation of the phenomenon of emulsions. As a result of this phenomenon, rocky aggregates without cover are not observed in the mixture, but the asphalt mixture's strength have decreased.

Stripping usually starts from the underlying layers of the asphalt and moves upwards. Poor pavement structure, under the traffic loads, creates cracks on the road surface, and in the advanced stages, asphalt begins to be crushed.

Tensile strength tests are used to investigate the effect of moisture damages on asphalt mixtures. Because when the wheel load of the vehicles is applied to the pavement, two major stresses are transferred to the asphalt layer, one of the compressive stresses perpendicular to the asphalt layer and the other horizontal stress under the asphalt layer. Therefore, the asphalt mix should have sufficient tensile strength to withstand tensile stresses in the asphalt layer. Also, at low temperatures, the water that penetrates the empty space of the asphalt will be freeze and also asphalt has affected by the expansion force due to freezing of water. As the temperature rises and the ice melts, the asphalt structure would collapse, and in this case the asphalt resistance decreases more than before. The set of these factors causes weakness and failure in the asphalt.

2- Definitions and Literature Review

Hydrated Lime (HM): The most effective anti-stripping agent which is available and used to eliminate the issues caused by moisture.

Anti-Stripping (AS): The phenomenon of breaking the bond between the bitumen and aggregates is known as anti-stripping.

Hot Mixture Asphalt (HMA): These group of mixtures are produced and distributed in high temperatures. The reason of using these temperatures is to make sure to that the aggregates are fully covered by bitumen in order to facilitate the compaction of the mixture.

Anti-Stripping Additives (ASA): Materials used to improve adhesion between asphalt and the aggregates which are chemically designed in both liquid and solid form.

Literature Review

In the past, there has been various experiments on evaluation of the moisture sensitivity which are introduced since 1930. These tests are used on compacted and non-compacted mixtures. The most important experiment of this period were LOTTMAN NCHRP-246 and NCHRP-192 and Root-Tunnicliff. Later, by merging these two methods, a more complete method known as MODIFIED-LOTTMAN was created and used extensively. This experiment has been codified under the standard of ASSHTO-T283 and is very popular. Some of these previous experiments are shown in Table 1.

Table 1. A comparison between non-compacted mixtures tests and compacted mixtures tests

Test method	Principles	Moisture damage index	Reference
Non-compacted mixtures tests			
Static-immersion	Floating uncompact mixture for a specific time in water	Assessment of anti-stripping area	AASHTO T182
Stripping test	Floating uncompact mixture in water and put in the experiment device for a specific time	The percentage of the whole stripped aggregate surface	CALIFORNIA 302
Texas Boiling Test	Floating uncompact mixture for a specific time in water	Estimating aggregates coverage	ASTM D36, KENNEDY AND CO.1982
Newmatic tension test	Tensile strength calculation and the bond of bitumen and aggregate	Tensile strength	Youtchev and Arouliv, 1997
Compacted mixtures tests			
Immersion-pressure test	Estimating the change in mixture stress-strength in vicinity to water	Saturated to dry stress-strength ratio	AASHTO T165-55
Main indirect tension test	Measurement of change in resilience module and tensile strength of mixture in vicinity of moisture	Indirect saturated to dry tensile-strength ratio	LOTTMAN 1982
Modified Lottman indirect tension test	Similar to original Lottman test, with a difference that the samples must be saturated up to 70-80 percent	Indirect saturated to dry tensile-strength ratio	AASHTO T283
Root-Tunnicliff test	Similar to modified Lottman test	Indirect saturated to dry tensile-strength ratio	ASTM D4867

3- Methodology

The main question of this research is the role of Hydrated Lime (HL) and Zycosil in reducing the stripping of Hot Asphalt Mixtures (HMA) and the use of these two substances as an additive in reducing the moisture sensitivity of asphalt. HMA samples modified with HL which contains different concentration of Zycosil were made and tested. The samples and control HMA sample were tested using AASHTO T283 standard for moisture susceptibility. To accommodate different moisture conditions for each type of mixture, six samples were divided into dry and saturated, in such a way that the average air voids were approximately equal.

4- Materials and Tests

4-1 Materials

Stone materials used to make pavements often contain some dust and harmful substances on their surface. The presence of these materials on the surface of aggregates reduces the rate of coating and softening the bitumen, and thus no proper bond would form between bitumen and rock materials. Due to the fact that the materials used in the test are Tuff rocks, this rock material has volcanic ash after sedimentation in sedimentary environments that create volcanic Tuffs. These aggregates have high water absorption and high porosity (Table 2, Table 3).

Table 2. Physical and resistive characteristics of Hot Asphalt Mixtures by Marshall method

Description	Heavy Traffic EAL>106		Medium Traffic 104<EAL<106		Low Traffic EAL<104	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Number of blows on both sides of the sample	75	75	50	50	35	35
Mix resistance in kilograms	800	-	550	-	350	-
Fluency in millimeters	2	3.5	2	4	2	4.5
Percentage of empty space for asphalt	3	5	3	5	3	5
The percentage of empty asphalt liners	3	6	3	6	3	6
Percent Free Space Base Asphalt	3	8	3	8	3	8
The percentage of empty space filled with bitumen	65	75	65	78	70	80

Table 3. Properties of used stone materials

Description	Test Result	Limits Allowed		Test standard	
		Liners	Surface	AASHTO	ASTM
Maximum wear by Los Angeles method (%)	22.3	40	30	T96	-
Maximum scoring factor by BS812 method (%)	9	30	25	-	-
Minimum fracture percentage Ii two faces on Sieve No. 4	94	80	90	-	D5821
Maximum water absorption (gravel aggregates)	2.2	2.5	2.5	T85	-
Maximum water absorption (fine aggregate)	2.4	2.8	2.5	T84	-

The bitumen used is this research is pure with a penetration rate of 60.70, which is supplied by the Pasargad oil company in Tehran. For the production of hot asphalt samples, this bitumen has been modified using hydrated lime additive. The type of bitumen and its characteristics are shown in the Table 4, and the mixed aggregates of used stone materials are shown in Table 5.

Table 4. Properties of used bitumen

Properties	Bitumen 60.70	Test method
Specific gravity at 25 °C	1.03	ASTM D-70
Degree of penetration at 25 °C	64	ASTM D-5
Softness Point (°C)	54	ASTM D-36
Ace at 25 °C	102	ASTM D-113
Flash point	305	ASTM D-92
Ignition point	317	ASTM D-70

Table 5. Mixed aggregates of used stone materials

Percentage of passing					Sieve Size (mm)	Sieve Number
Grading 5 (D)	Grading 4 (U)	Grading 3 (M)	Grading 2	Grading 1		
-	-	-	-	-	25	1 in
100	100	100	100	-	19	3.4 in
92	92	92	90	100	12.5	1.2 in
82	85	82	-	-	9.5	3.8 in
51	66	58	44	74	4.75	4 in
32	50	41	28	58	2.36	8 in
24	38	31	-	-	1.18	16 in
17	27	22	-	-	0.6	30 in
10	18	13	55	21	0.3	50 in
7	12	8	-	-	0.15	100 in
5	8	5	2	10	0.075	200 in

4-2 Tests and Results

4-2-1 Marshal test

To obtain the Marshall resistance, Marshall samples were placed in a hot bath at 60 °C for 30 minutes, and then the samples were taken out and placed between the jaws of the Marshall Testing Machine. The maximum force applied to the sample before it cracks which is called Marshall Resistance.

According to the above mentioned test method, the Marshall Resistance of the samples can be calculated. The Marshall Test is a type of destructive test, so, bulk density and the percentage of free space tests should be done before the test. Six different samples were used for each test. On half of the samples, the Marshall resistance test was carried out in 30 minutes in 60°C water and on the other half at 24 hours in 60°C. The results of this experiment are presented in Figure 1. By analyzing the results, it is shown that the sample containing 3% solution of hydrated lime has the highest resistance in both dry and saturated conditions. The lowest Marshall resistance is in a dry state in non-additive samples. By increasing the percentage of hydrated lime, the amount of this resistance increases, which can be due to chemical and physical interactions between bitumen and lime, that causes the bitumen to become harder and causes more bonding of the mixture and ultimately endurance and strength of the samples. In saturated specimens, the highest resistance is related to the samples containing 3% hydrated lime. This indicates that the mixtures containing this additive are stronger in terms of moisture and water. The mixture contains 2 percent lime and 0.05 percent Zycosil at a short interval thereafter, indicating a reaction between the lime and bitumen in the mixture, thereby reducing the moisture sensitivity of the mixture, and this additive can be used at a relatively low cost in asphalt mixtures to reduce the moisture sensitivity of these mixtures and greatly reduced the premature damage to asphalt pavements. On the other hand, mixtures containing 0.1% Zycosil have a lower amount than the results of other additives. This indicates that the Zycosil additive reduces the viscosity of the bitumen, which ultimately results in the production of a mixture with lesser hardness.

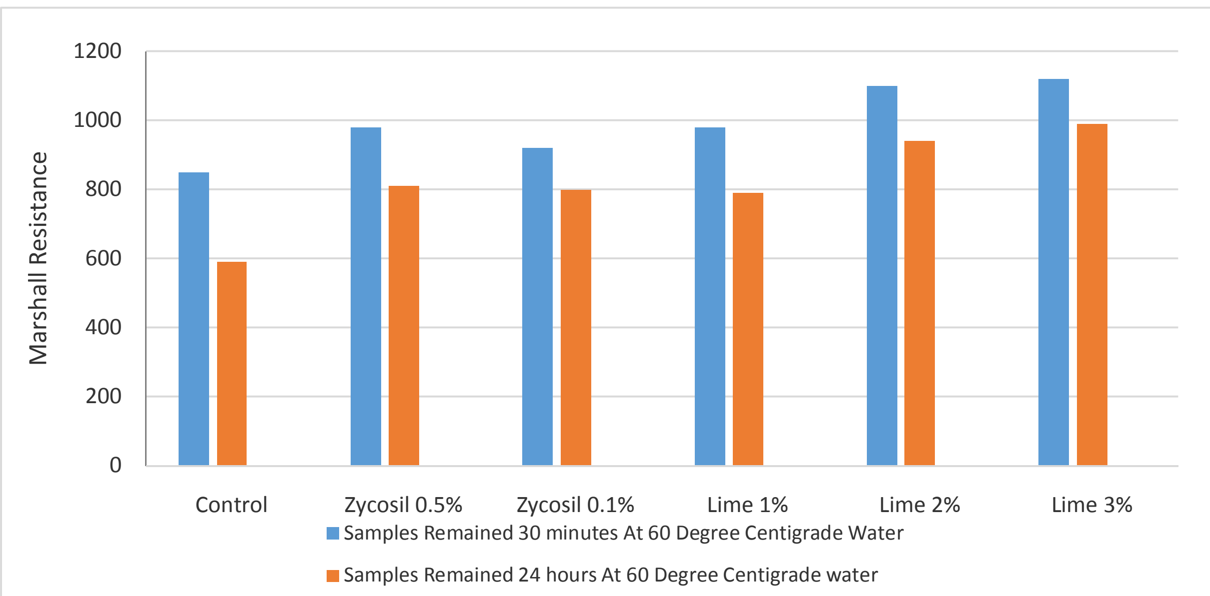

Figure 1. Result of Marshall resistance of samples

4-2-2 Hamburg wheel trail effect test

The Hamburg Wheel track Device was made by the Willmott-Wind GmbH in Hamburg, Germany, which is depicted in Figure 2. At each test time, a pair of samples measuring 260 mm wide, 320 mm long, 40 mm thick are tested simultaneously. All specimens are packed with a percentage of free space between 6% and 8% using rubbing densifier and placed in a water bath at a temperature of 50 °C. Steel wheels with a width of 47 mm apply loads of 705 (N) on the specimen. In this case, wheels shuttle at a speed of 50 per minute. Each sample passes through 20,000 wheels or reaches a depth of 20 mm. Each test takes about half to six hours.

Hamburg wheel trail effect test result

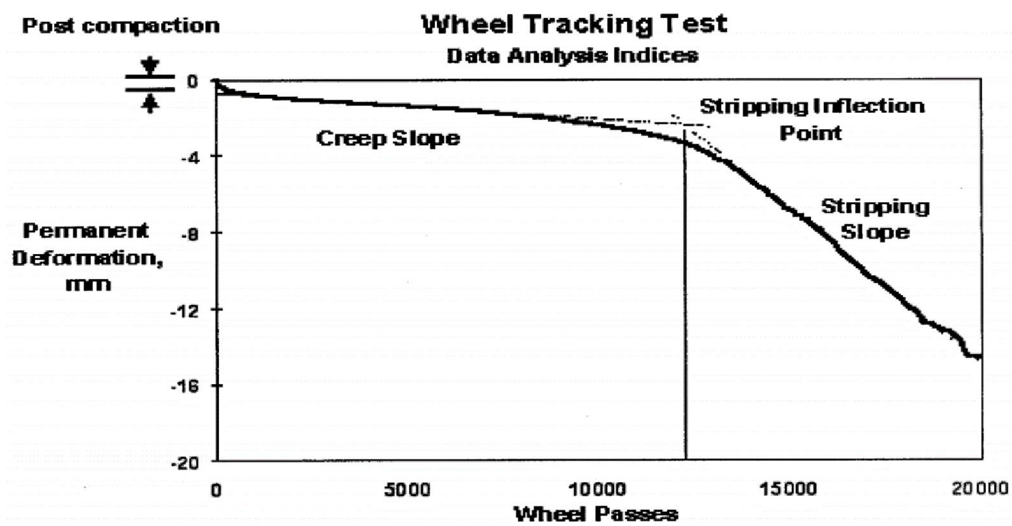

Figure 2. Hamburg test result

In Figure 3, it is observed that different specimens have the same bulk density and have a slight difference in comparison to each other. Also, it is shown that the bulk density obtained with the results of the percentage of free space has an opposite trend to each other and if one increases, causes another to decrease.

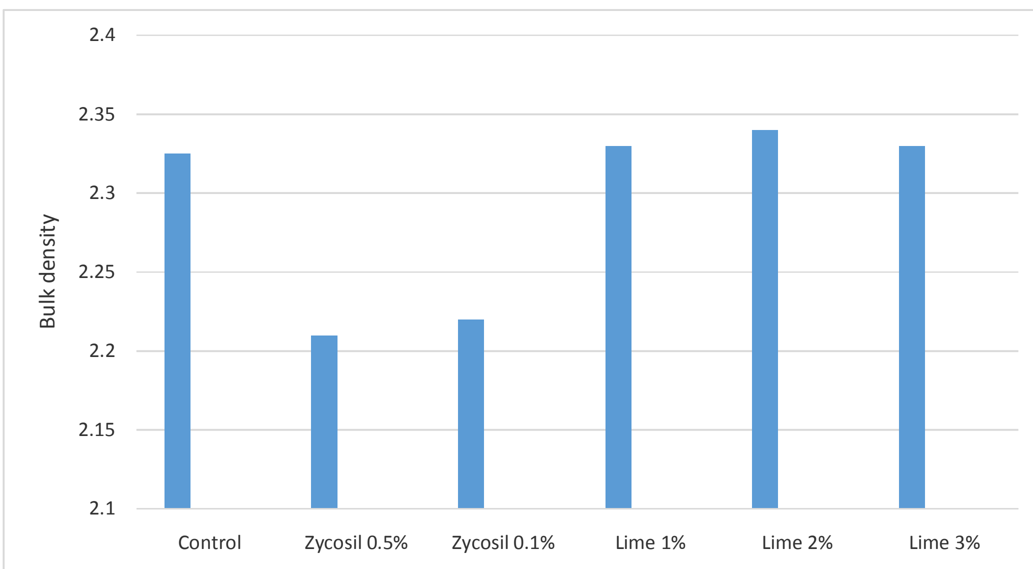

Figure 3. Bulk density of samples

In Figure 4, by examining the results, it is observed that the percentage of free space of all specimens is between 3 to 5%, which is within the permitted range of regulations. All specimens except the specimen containing 3% HL have a lower percentage of free space than the control mixture, which can be due to more hardening of bitumen containing high percentage of HL compared to the control mixture, which prevents from more compaction of the mixture and therefore the higher porosity percentage. The process of increasing the percentage of free space by clearly adding the amount of lime is clearly visible. On the other hand, by adding a higher percentage of zycosil, the amount of free space in the mixture decreases. This can be due to a reduction in bitumen slow-flow due to the presence of a higher percent zycosil solution, which can be effective in reducing the free space of the samples. This reduction in free space can increase the workability of the mixture in the field density and, by applying less force, the required density is achieved. Besides, the percentage of low free space will reduce the air and water penetration into the asphalt mix, which itself can reduce the aging process of the mixture and reduce its stripping.

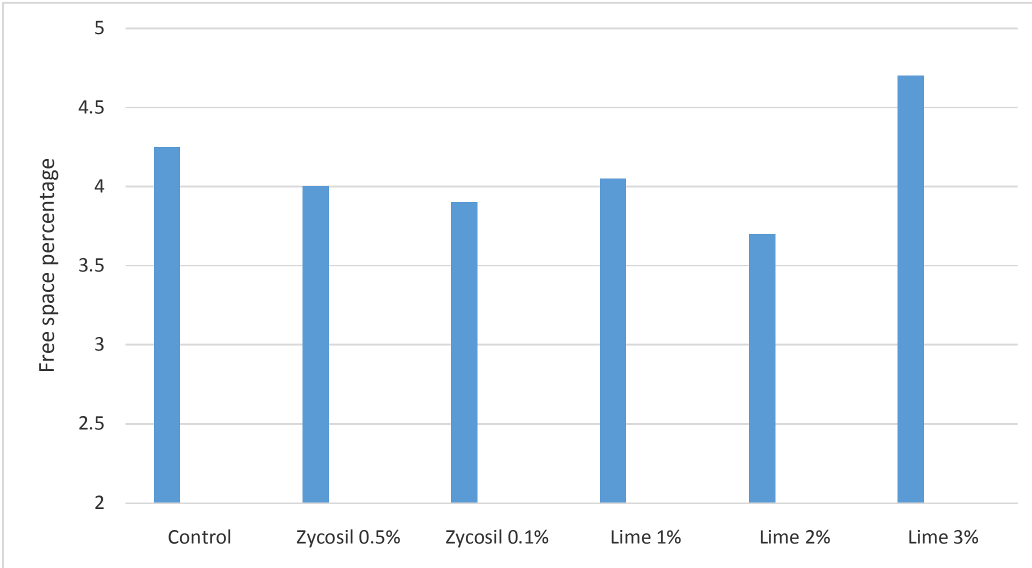

Figure 4. Free Space Percentage

In Figure 5, the test was carried out according to the standard AASHTO T283-03 by an indirect pulling device. For each of the mixtures, six cylindrical samples were prepared. Three samples were used for testing under dry conditions (unsaturated) and three for testing under saturated conditions. The ratio of the resistance of the saturated samples to the dry (unsaturated) samples results in the TSR value. The results obtained in Figure 5 show that samples containing 3% lime have the highest ITS in dry form, and then the mixture contains 2% HL. From the analysis of these results, it can be concluded that mixtures containing 3% lime exhibit a much higher cohesion than the rest of the samples, which can be due to the lime hardening the bitumen. By observing the results of the saturation state, mixtures containing various percentages of HL have the highest indirect tensile strength compared to the control mixtures. By analyzing these results, it can be proved that mixtures containing lime with high percentages have a good reaction to bitumen and rock materials, which leads to maintaining their resistance against the effects of moisture and water and prevent the collapse of the mixture. Adding these additives improves the bond between the rock and bitumen as well as the bitumen and bitumen bond, which is the first to enhance the adhesion of the bitumen and mixed rock materials, and cohesion of the whole mixture.

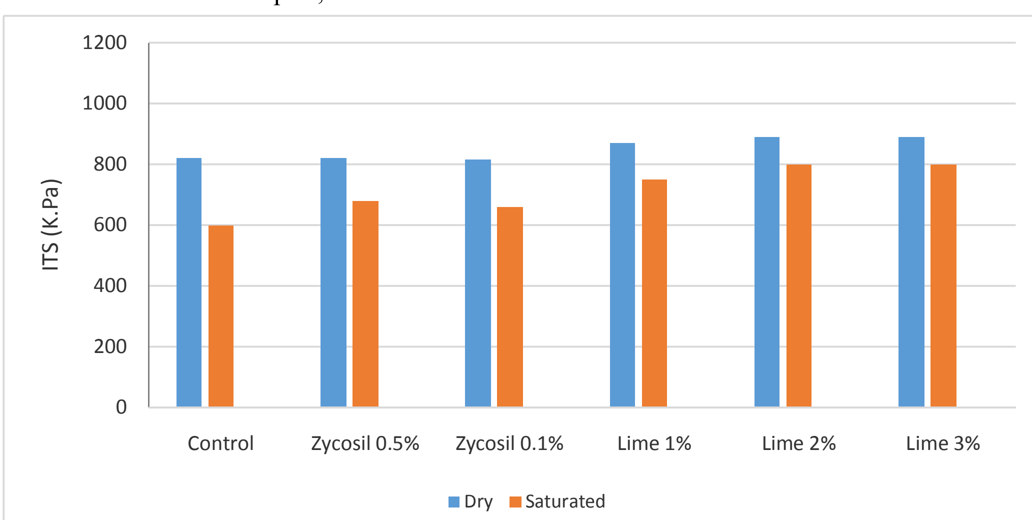

Figure 5. Indirect Tensile Strength of samples

In Figure 6, By examining the results of the tensile strength of the tested specimens, the sample containing 3% lime has the highest ratio among all the mixtures, which indicates a lower reduction of the tensile strength of the samples under the influence of the effects of moisture and water. This high ratio can be due to the presence of an active linkage of lime and bitumen as well as aggregates, which makes it resistant to moisture damaging effects. Samples containing 1% lime as well as Zycosil additive samples have a higher resistance to the control samples, indicating a positive effect of these additives in the asphalt mixtures of the study.

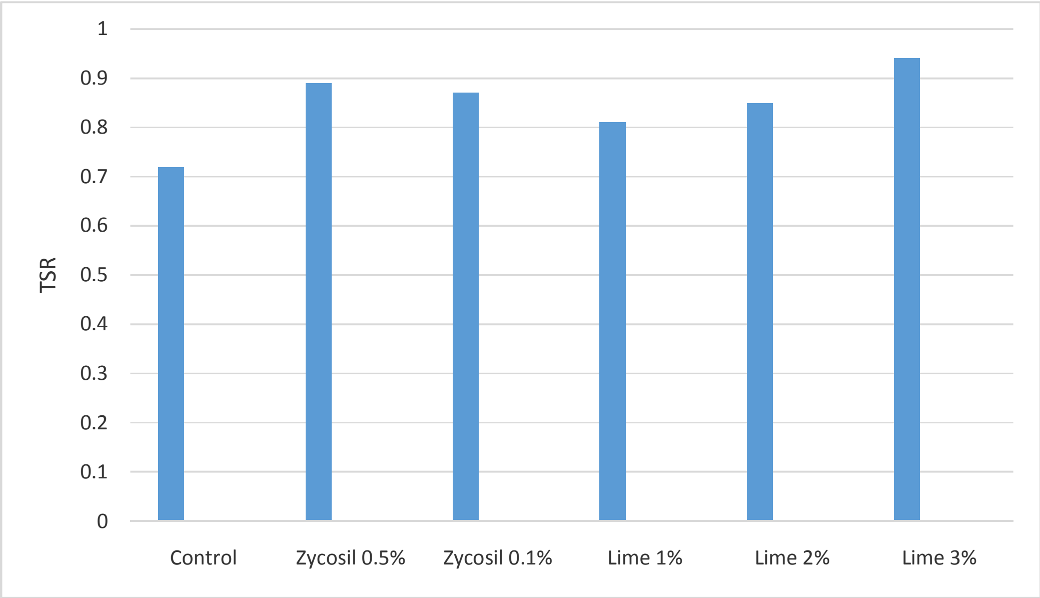

Figure 6. Tensile Strength Ratio of saturated-to-dry of specimens

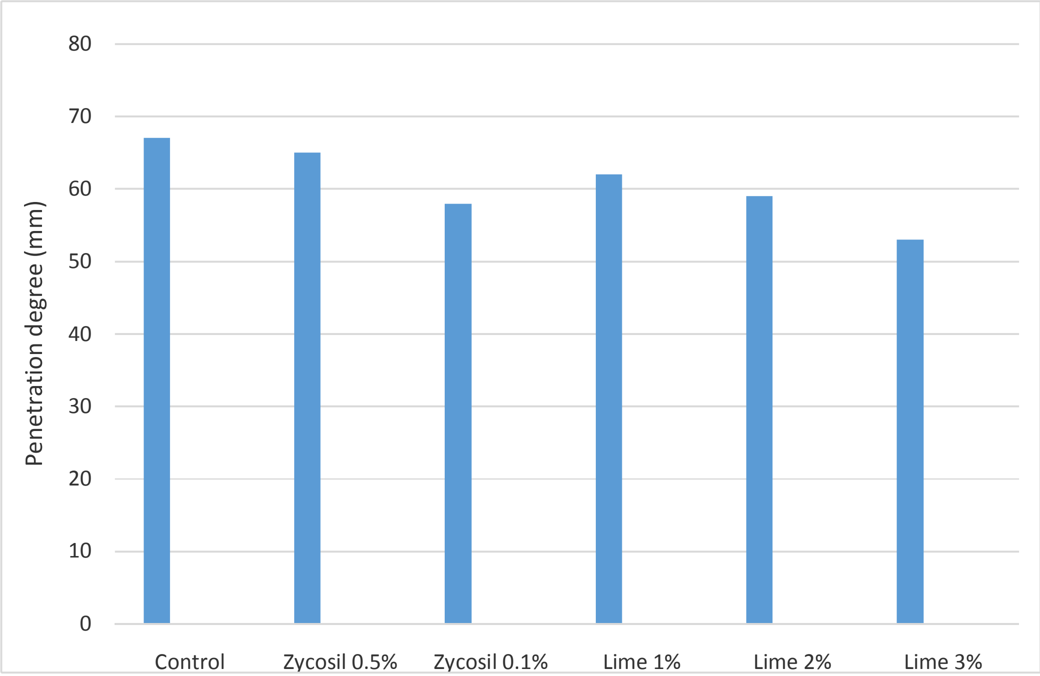

Figure 7. Penetration degree of samples

In Figure 7, the results of the test show the degree of penetration on the samples containing two additions of HL and Zycosil with different percentages. It's noteworthy that the additives percentage is considered to bitumen weight. The degree of penetration testing is one of the tests used to determine the concentration and consistency of bitumen properties. By examining these results, it can be noticed that by increasing both additives, samples containing them will decrease their degree of penetration. This indicates hardening of bitumen at 25°C. This hardening is due to a change in the molecular structure of bitumen in contact with these two additives.

In Figure 8, by examining the results, it can be distinguished that, unlike the degree of penetration which decreases with increasing the amount of additive, in this case, with the increase of the amount of both additives, the softness point of the samples containing these two additives is increasing. It is also observed that this increase in the softness point is higher for samples containing hydrated lime, and the sample containing 3% hydrated lime has the highest softness point among the samples. This indicates hardening of bitumen exposed to HL.

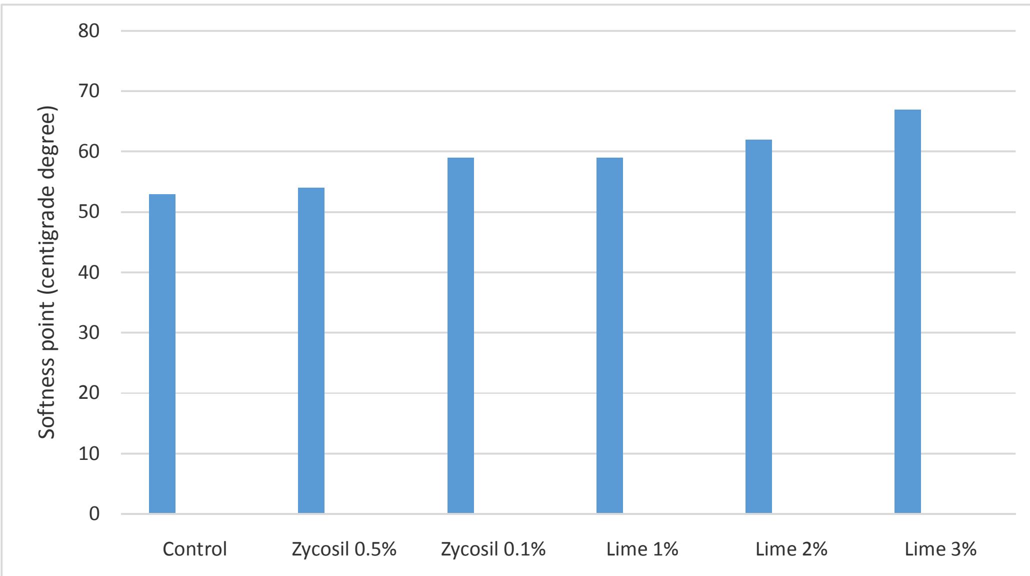

Figure 8. Result of softness point of samples

In Figure 9, by analyzing the results, it is observed that samples containing Zycosil tend to decrease and then tend to increase. Unlike this additive, samples containing HL follow a decreasing trend, which results in a decrease in bitumen stretch ability with an increase in the amount of this additive. But in the case of Zycosil additive, the results are reversed and as the amount of this additive increases, the bitumen stretch ability increases.

By examining the results of the experiments carried out in this study, it can be concluded that hydrated lime and Zycosil alter the polarity and non-polarization of aggregate surface molecules, which can lead to increased bitumen capability on stone aggregates. This results in a complete coating of bituminous aggregates and reduces the sensitivity to stone debris. On the other hand, the increase in the percentage of Zycosil additive causes softening of the bitumen, which leads to a decrease in the strength of the mixture against permanent deformations, which should be carefully selected in the mixing plan for asphalt mixtures. In addition, increasing the percentage of HL causes hardening of bitumen, which, on the one hand, improves the bonding properties of the mixture and improves performance against permanent deformations, and on the other hand, this hardening reduces the mixing efficiency and leads to a mixture with higher percentage of empty space. This percentage of high vacant space leads to the flow of more water and air into the pavement and leads to weakening and decay of the pavement in the long run. Therefore, the percentage of this type of additive should be selected and taking into account all conditions of production and performance in the short and long term.

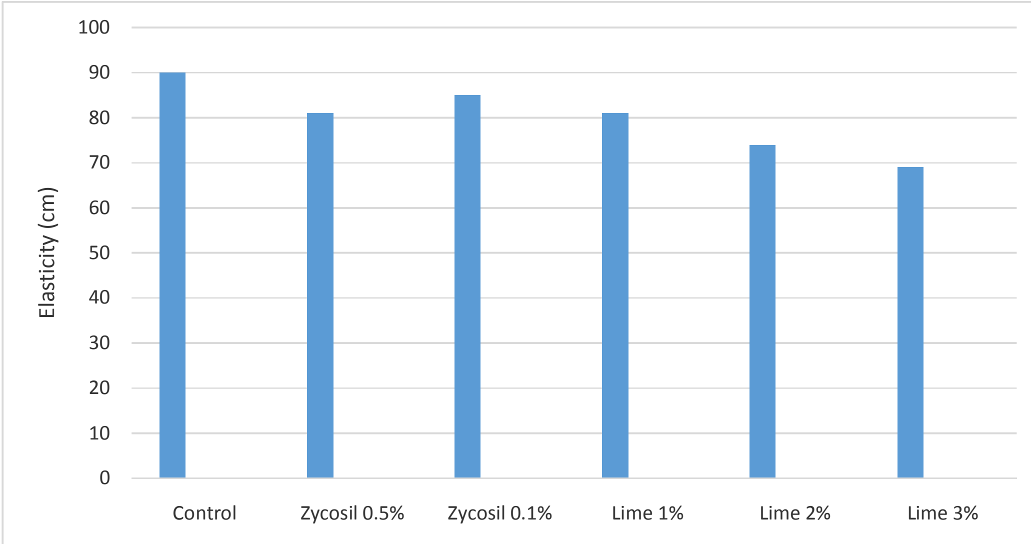

Figure 9. Elastic Result of samples

5- Conclusion

The main objectives of this research were investigation and analyze of mechanical properties of modified and unmodified mixtures. Adding the modifier to pure bitumen would improve the viscoelastic behavior of bitumen and would change its rheology properties. In this research, two types of bituminous modifiers have been used to change the rheology properties of bitumen, which include hydrated lime and Zycosil. After testing on the asphalt mixtures prepared with these two additives and comparing the results obtained from the experiments, the following results are obtained:

According to the results of the percentage of free space, the samples containing zinc oxide additive and samples containing 1 and 2% hydrated lime have less free space than the control blend samples, which is due to the decrease of bitumen viscosity in these types of mixtures that reduces the pores are mixed and eventually reduce the flow of air and water into the asphalt mixture, which itself can reduce the aging process of bitumen and the moisture sensitivity of the mixture. The positive effects of this phenomenon can be attributed to the reduction in energy required for hot mix asphaltic mixtures to reach the density required for such mixtures.

The results of the Marshall resistance of the specimens were observed in both dry and saturated conditions, which showed that Zycosil additive and hydrated lime mixtures with a 2% and 3% percent had a higher resistance to the control mixtures. In saturated state, all specimens have more resistance than control mixtures, which indicates less moisture effect on hot asphalt mixes, and Marshall resistance reduction in samples containing these additives is lower than that of control. By analyzing these results, it can be concluded that the presence of these additives increases the bonding of the mixture and thus improves the resistance of these mixtures.

In the test of indirect tensile strength, samples containing 3% hydrated lime have the highest dry resistance. In this case, samples containing 1 and 2 percent hydrated lime have a slightly less resistance than samples containing 3 percent hydrated lime. By examining the results of this type of mix in saturated state, all the mixtures have a higher tensile strength than the control samples, which indicates a decrease in the effect of moisture on such mixtures. In this case, the sample containing 2% of hydrated lime has the highest tensile strength among all the mixtures. By analyzing these results, it can be concluded that the presence of hydrated lime and zinc oxide additives improve the moisture sensitivity of heated asphalt mixtures, which can be due to the effect of these two additives on the adhesion and cohesion properties of these mixtures.

By examining all the results of this study, the positive effect of additive of 2% hydrated lime and 0.05% Zycosil can be found in all experiments, which show a better behavior than the rest of the samples.

According to the results, the lime additive in low percentages improves the moisture sensitivity of asphalt mixtures, but in higher percentages, due to increased viscosity of the bitumen, mixing and compacting is difficult to do and this increases the percentage of free space. However, in liquid additives, Zycosil, in addition to improve the moisture sensitivity of the asphalt mix, it reduces viscosity and results in better compaction.

Suggestions

For future studies, the following suggestions are presented:

- Investigating the effect of these two additives on the properties of pure bitumen by Sharp Tests;
- The effect of moisture on the fatigue properties of asphalt mixtures;
- Investigating the effect of different bituminous materials on moisture sensitivity of asphalt mixtures;
- Investigating the effect of different vacant spaces on the unaged and aged properties of asphalt mixtures;
- Using scanner images of an electron microscope to evaluate bitumen adhesion to rock materials;
- Further research on the moisture sensitivity of the mixtures by the effect of the Hamburg wheel trail test and also the APA test;
- Modeling these types of mixtures using the finite element method and validating it.

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