International Journal of Engineering Innovation & Research
Volume 3, Issue 6, ISSN: 2277 – 5668

An Examination of the Effect of Bitumen Content on the Performance of Moisture Susceptibility of Asphalt Mixture Under Freeze-Thaw Cycles

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Abstract – **The asphalt layer of pavement constitutes the most important part of pavement because of its direct exposure to various damaging factors including weather changes and traffic loads. For this reason, researchers have always tried to find methods to reduce damages and lower the costs of repair and maintenance. In cold and freezing weather, the surface layer of pavement is exposed to intense stresses, which increases the risk of damage. In cold areas, moisture susceptibility is a critical factor in damaging the surface layer of asphalt. Little research has been conducted on the bitumen content as a factor reducing moisture susceptibility. In this study, the effect of bitumen content on moisture susceptibility in freezing and cold weather and under freeze-thaw cycles has been examined and the changes in moisture susceptibility have been compared to those in the specimen made with optimum bitumen content. To this end, asphalt mixtures with various bitumen content were prepared and subjected to Marshall Immersion Test and Indirect Tensile under various cycles. The results show that as the number of cycle increases, the resistance of the specimens reduces and as the increases in the bitumen content, the reduction becomes less. Also, the specimens with a higher bitumen content than that of optimum bitumen content show less moisture susceptibility.**

Keywords – **Asphalt Mixture, Bitumen Content, Moisture Susceptibility, Indirect Tensile Strength, Freeze-Thaw Cycle.**

I. Introduction

Researchers have always tried to design asphalt pavement that has the highest durability in various climatic and environmental conditions. To optimize the function of asphalt pavement is to enable it to resist damages. In cold areas, temperature and moisture are two main damaging factors. The asphalt mixture is a viscoelastic material which is affected by temperature [1]. As a viscoelastic material, bitumen plays a prominent role on determining many aspects of road performance [2]. In cold weather, it is subjected to intense stress, and becomes susceptible to damages, so the mixtures used in cold and warm areas are different.

Normally, bitumen is adhered to aggregate materials in the absence of water without any problems, but since aggregate materials absorb water faster and better than bitumen, therefore not only the presence of absorbed water creates damages to the adhesion of bitumen to aggregate materials but creates various problems leading to weakening or damaging bitumen and materials. This kind of damage, since it is either directly resulted from moisture or is aggravated by moisture, is referred to as moisture susceptibility [3]. Damage through moisture is a major failure in asphalt pavement, especially in cold areas, which consists of loss of resistance and durability in asphalt mixtures; it is made of two basic processes of loss of adhesion and loss of cohesion [4]. Loss of adhesion happens when water is trapped between bitumen and aggregate and results in the separation of bitumen from the aggregate surface. And loss of cohesion happens when water and bitumen are mixed, resulting in a change in the properties of bitumen. Moisture susceptibility can be the result of either of these two processes or a combination of them [5].

Various factors affect the amount of damage resulting from moisture. Some of these factors are related to the mixture materials forming hot mix asphalt such as aggregates (physical characteristic, composition, dust and clay coatings) and bitumen (chemical composition, grade, hardness, crude source, and refining process). The other factors related to mixture design and construction environmental and traffic condition and properties of additives [6]. As a result of the existence of water in pavements, water is trapped between the bitumen film and the aggregate materials surface, and since the latter has a stronger tendency to absorb water, the adhesion is weakened and the inner resistance of the asphalt mixture is reduced, resulting in rapid development of rutting and fatigue cracks [7]. Another damage resulting from the bad effects of the water lie in the displacement of asphalt film and causing structure damage through the volume expansion when temperature decreases [8].

There are many methods to examine moisture susceptibility of asphalt mixtures. The most common of these methods include: Marshall Immersion Test, Boiling Water Test, Static Immersion Test, Littman and modified Littman. However, several disadvantages are associated with the current test methods, and the effectiveness of these procedures has been questioned [9].

How to reduce the damages caused by asphalt mixture after a freeze-thaw cycle still remains a problem [7]. Therefore attempts have been made to offer a better estimation of moisture susceptibility of the asphalt mixture by improving testing methods and procedures [10]. Aimed at a better understanding of moisture damages of asphalt mixtures, other studies have examined the concepts related to the key properties of materials such as fracture parameters, surface energy, air void, penetration coefficient and adhesion specifications. Also, other studies have been done on using different additives for decreasing moisture damages to asphalt mixtures, which shows that anti-stripping additives can have a positive effect on the adhesion of bitumen to aggregates and, in general, decrease moisture susceptibility.

Pavements disposed to cold weather have less compressibility and have more air cavities than the pavements disposed to warm weather. This could increase pavement susceptibility to moisture damage [11]. Since moisture susceptibility is a critical and determining factor in preparing asphalt mixtures in cold areas, the aim of this research is to reduce this determining factor without using additives and by using the research on the effect of bitumen content parameter on producing specimens for decreasing moisture susceptibility at different cycles. To this end, specimens are produced with various bitumen content and optimum bitumen content (OBC) and are subjected to different freeze-thaw cycles and the effect of various bitumen content on moisture susceptibility of the specimens and the changes are studied.

II. Material and Methods

The aggregates used in this study are crushed limestone whose specifications are stated. The grading of aggregate materials is the Topeka cohesive grading of hot asphalt mixture. In this research, neat bitumen of 85/100 penetration grade has been used in all specimens. The full specifications are shown in Table 2.

Table 1: Engineering properties of aggregates

Properties	**Value**	
	Coarse	**Fine**
L.A abrasion (%)	36	-
Absorption (%)	3.2	4.3
Bulk specific gravity (g/cm3)	2.55	2.48
Apparent specific gravity (g/cm3)	2.62	2.59

Table 2. Properties of the bitumen used

Properties	**Specification**
Specific gravity @25/25 ℃	1.02
Penetration @25 ℃ (0.1 mm)	93.7
Softening point (℃)	46
Ductility @25 ℃ (cm)	100 min
Loss on heating (%)	0.5 max
Flash point (℃)	232

III. Specimens Preparation and Testing Methods

The asphalt mixtures were conducted by using the standard Marshall Mix design procedure with 75 blows on each side of specimens. Marshall Specimens were compacted and tested according to bulk specific gravity (ASTM D2726) [12], stability and flow test (ASTM D1559) [13], and maximum theoretical specific gravity (ASTM D2041) [14] standard procedures. The optimum bitumen content was found to be 5.2% by weight of aggregate for the asphalt mixtures. Specimens were prepared with 4.5%, 5%, 5.5%, 6% and 5.2% (OBC) bitumen content. For the Marshall Stability and flow test and indirect tensile stiffness modulus test, the specimens were compacted by using 75 blows on each side of cylindrical specimens at 4±0.5% air void. As for the indirect tensile strength test the specimens were compacted in order to have 6–8% air void.

IV. Marshall Immersion Test

At first, Marshall Specimens were prepared using Marshall standard hammer with 75 impacts on each side of the specimen. Two groups of compressed specimens were used in this method. The average specific weight of the three groups must be equal. The first group was put in a water bath of 60℃ for a period of 30 minutes. The second group was also put in a water bath of 60℃ but for a period of 24 hours, according to standard (AASHTO T165) [15]. A pressure with destruction accelerate rate of 51 mm/min was applied to both groups at 25℃ and Marshall Flow and stability are registered. Marshall Quotient was calculated by measuring Marshall Flow (mm) and stability. Marshall Quotient is an appropriate criterion for strength of materials against shear stress, permanent deformations and also rutting [16]. The high percentage of Marshall Quotient shows the high level of hardness of asphalt mixture and its high ability in expansion of input load and also resistance to creep deformation [17]. Retained Marshall Stability (RMS) is calculated using the average stability of each group using the following relation:

$$RMS = \frac{MR_2}{MR_1} \times 100 \qquad (1)$$

Where MR_1 is Marshall Stability average for dry specimens and MR_2 is Marshall Stability average for specimens taken after the conditions have been applied. It is used as an index for moisture susceptibility of asphalt mixture. The minimum amount of RMS for prevention of moisture damage must be 70%.

In the Marshall immersion test, 30 specimens with 4.5%, 5%, 5.5% and 6% bitumen content and optimum bitumen content with 5.2% were used. The specimens were divided into two groups. The first group was put in dry conditions and the second group under AASHTO T165 standard conditions for applying moisture conditions. For both groups Marshall Stability parameter in immersion (MR) and flow modes were registered and the Retained Marshall Stability (RMS) was determined in each cycle.

V. Indirect Tensile Stability Test

The aim of modified Littman test (AASHTO T283) [18] was to evaluate the susceptibility of asphalt mixtures against moisture damages [19]. This standard offers a way for preparing specimens and measuring changes of diagonal tensile strength of specimens caused by the effects of saturation and freeze-thaw conditions on the asphalt mixture specimens in the laboratory [20]. This test compresses the specimens to achieve air void ratio of

%7±1. Then the compressed specimens with different bitumen content - three specimen in dry conditions and three specimens under saturation conditions (70-80%) - are tested after they are subjected to a freeze-thaw cycle. A cycle consists of 16 hours of freeze in -18̊C temperatures and a 24-hour 60̊C water bath. Indirect tensile strength test is done on specimens with loading ratio of 50 mm/min; the ratio is calculated using the following relation:

$$S = \frac{2P_{\max}}{\pi D t} \qquad (2)$$

Where Pmax is the maximum applied load and D is the diagonal of specimens and t is specimen's average height.

Moisture susceptibility of specimens is calculated using the following relation by calculating tensile strength (TSR):

$$T = \frac{S_2}{S_1} \times 100 \qquad (3)$$

Where S_1 is indirect tensile stability average for dry specimens and S_2 is indirect tensile strength average for specimens applied after the completion of freeze-thaw cycle. The minimum level of TSR for prevention of moisture damage must be 80%.

VI. Freeze-Thaw Cycle Test

The freeze-thaw is a natural phenomenon which can have a destructive effect on the pavement under special circumstances. When the pavement is exposed to freezing condition, the inflation caused by the freeze-thaw and the failure caused by the increased volume of the water penetrated into the inner layer of the pavement can cause damages.

Sixty specimens were used in the indirect tensile test, which, like Marshall Immersion test, were prepared using specimens with different bitumen content. Each of the specimens with different bitumen content was subjected to 0, 1, 2, 4, 6 and 8 freeze-thaw cycles.

VII. Determining the Optimum Bitumen Content

To determine the optimum bitumen content, the bitumen content with 4.5%, 5%, 5.5% and 6% have been used in the preparation of specimens of asphalt mixtures. Given the results of the Marshall tests, the optimum bitumen content for asphalt mixture was determined to be 5.2%.

VIII. Marshall Immersion Test Results

The results are shown in Figures 2-4. They show Marshall Stability, (RMS) ratio of Retained Marshall stability and Marshall Quotient respectfully. In the Figures, the results for each bitumen content have been shown with a separate color and 0 cycle refers to tests done on specimens without moisture conditions. These figures present the mean obtained from the three tests conducted on the specimens.

As shown in figure 1, Marshall Stability of all specimens was reduced after moisture conditions were applied. Also, this figure shows the effect of bitumen content on Marshall Stability of specimens. As we can see, an increase in the bitumen content will lead to less reduction in the stability of specimens. Also, as the bitumen content goes higher than the optimum bitumen content, the initial Marshall stability of specimens reduces. But the specimens with a higher bitumen content than optimum bitumen content will have higher Marshall Stability after the application of cycles, to the point where Marshall Stability was reduced by 8% in the specimens with 6% bitumen content. This reduction is 29% for the specimens made with optimum bitumen content of 5.2%. This happens because the air voids between the aggregates are filled with bitumen and as a result less water penetrates into the specimens.

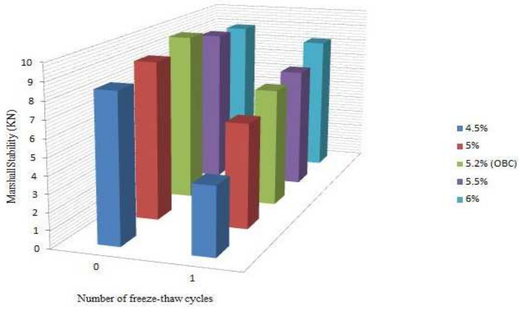

Fig.1. Marshall Stability values of the specimens before and after freeze-thaw cycle.

Figure 2 shows the relation between Retained Marshall Stability and bitumen content in the specimens: the latter increases as the former increases. This increase is non-linear since by increasing the bitumen content from 4.5 to 5, the retained Marshall Stability increases by 20%. This increase is only 11% for the specimens made with 5.5% of bitumen.

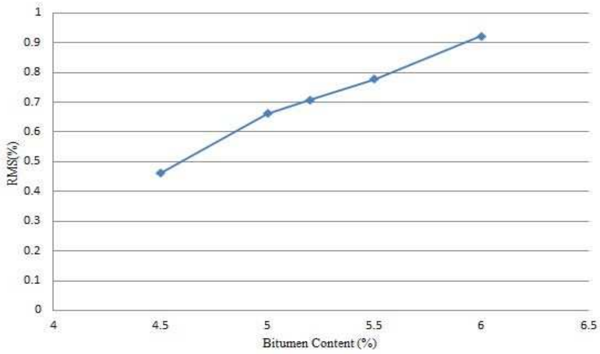

Fig.2. Effect of freeze-thaw cycle on Retained Marshall stability.

Figure 3 shows Marshall Quotient in the initial conditions and also after the application of the moisture conditions. As shown in this figure, the Marshall quotient reduces for both specimens (after and before the application of moisture conditions). The reduction is less in specimens made with higher bitumen content, which shows that specimens made with higher bitumen content lose less stability upon the application of moisture conditions and have higher stability against permanent deformation.

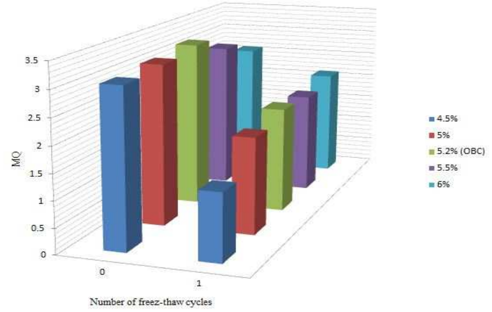

Fig.3. Marshall Quotient values of the specimens under freeze-thaw cycle.

IX. Indirect Tensile Tests Results

Figures 4 and 5 show the stability of indirect tensile of specimens and relation of indirect tensile stability (TSR) of specimens with 4.5, 5, 5.5 and 6% bitumen content and optimum bitumen content (5.2%) under different cycles respectively. The amounts stated in the figures represent the average of three specimens. Figure 4 shows the effect of bitumen content on decreasing the stability of indirect tensile of specimen under different cycles. Also, the stability of indirect tensile of all specimens reduces as the number of cycles increases. This reduction is due to the loss of mixture adhesion or cohesion of bitumen. In the initial cycles, the stability decreases drastically but then the decrease rate will slow done. This decrease will be much less in specimens with higher percentage of bitumen. In fact, the stability decrease in the first cycle is due to the expansion of water as a result of a rise in temperature, which causes microscopic fractures in the specimens and drastic decrease in their stability. In the subsequent cycles, after the holes are expanded enough and are connected to each other, water flows in the holes due to temperature gradient. Thus damages from the expansion of water decreases and the specimens lose less stability. In fact, an increase in the specimen's bitumen content improves the cohesion and adhesion of the mixture, preventing water from being replaced with bitumen on the surface of the aggregates. As is clear from the figure, the specimens produced with 5.5 and 6 bitumen content show a better performance against applied cycles and have less moisture susceptibility than the specimens produced by optimum bitumen content (5.2%).

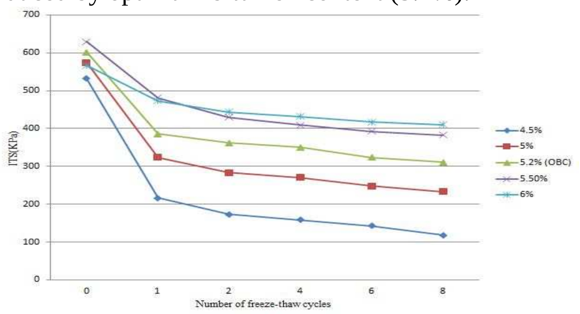

Fig.4. The variation in the ITS of the specimens under different freeze-thaw cycle.

Figure 5 shows the amount of TSR in different cycles. As shown here, TSR decrease by 60% after 2 cycles in the specimens with optimized bitumen but then slowly reaches 51%. This amount for specimens with 6% bitumen is 78% and 72%. Therefore the effect of bitumen on the function of asphalt mixture under freeze-thaw cycles is very important.

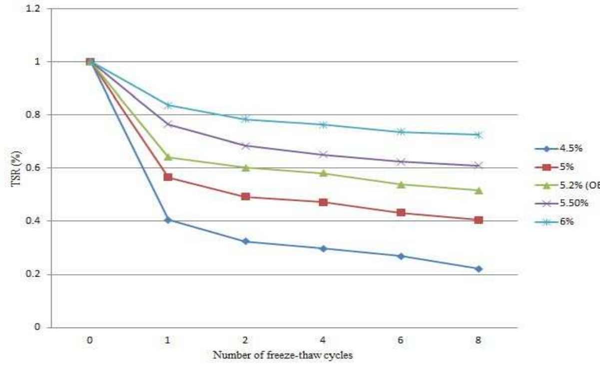

Fig.5. Impact of freeze-thaw cycle on tensile strength ratio of the specimens.

The test results show that the function of all specimens decreases as the number of cycles increases. This decrease in stability can be divided into two kinds, firstly the rapid decrease of stability in initial cycles and then the slow decrease of stability after the second cycle. The damage in initial cycles is due to the expansion of water in the mixture resulting from temperature changes. On the other hand, the moisture susceptibility of specimens decreases as bitumen content increases. Therefore, in cold areas, moisture susceptibility is the main and critical factor responsible for asphalt damages. This susceptibility can be improved by using more optimized bitumen. It is to be noted that other effective factors on the payment must also be taken into account.

X. Conclusion

This study examined the performance of asphalt mixtures with various bitumen content under 1, 2, 4, 6 and 8 freeze-thaw cycles. The results are as follows:

1. Bitumen content has an important effect on the performance of the asphalt mixture. With the grading used in this study, the mixture shows a better performance in higher bitumen content under freeze-thaw cycles. After 8 cycles, TSR increases from 51% to 72%. Thus using bitumen with a higher content than optimum bitumen content improves the moisture performance of the asphalt mixture.
2. As the number of freeze-thaw cycles increases, ITS and TSR decreases, so that an increase in the bitumen content will reduce reduction in various cycles.
3. The damages resulting from cycles can be divided into two kinds: a reduction of resistance in the first cycle as a result of water expansion in the specimens due to a rise in the temperature, which in turn results in a drastic decrease in the resistance of the specimen. In subsequent cycles, after the cavities become big enough to join, water

flows in them. Thus the damage resulting from water expansion reduces and resistance will subsequently reduce less.

4. The results of Marshall test show that while using a higher bitumen content reduces resistance and the Marshall quotient before moisture affects, after the effect of moisture, the specimens with a higher bitumen content show better resistance against permanent deformations. As the bitumen content increases, moisture susceptibility reduces and specimens with a higher bitumen content show, under moisture conditions, a better performance than the specimens with an optimum bitumen content. The performance improvement does not change in proportion with the increase in bitumen content. Thus in areas in which moisture susceptibility is the main damaging factor, the situation could be improved by increasing the optimum bitumen content. It is to be noted that other damaging factors should be taken into account as well.

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