

Effects of using asphaltite as filler on mechanical properties of hot mix asphalt

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ABSTRACT

This study focuses on determining the engineering characteristics of hot mix asphalt using mineral filler with asphaltite. Since asphaltite which consists of high amount of sulfur leads to air pollution when used as a heating material and also being hydrocarbon sourced, it seems better to use asphaltite in the hot mix asphalts. The hot mix asphalts in this study were prepared by using 25%, 50%, 75%, and 100% mixing ratios based on the mineral filler ratio to analyze the possibility of using asphaltite. The results reveal that using asphaltite as a whole filler significantly increased the retained Marshall stability by 27% and increased the stiffness modulus by 91% at 15 °C. As for the tensile strength test, it was determined that the control mixtures lost 35% of its tensile strength ratio after one freeze–thaw cycle, however the mixtures containing completely asphaltite as filler lost only 13%. A remarkable increase was found at fatigue test. The cycle number leading to failure of the mixtures containing 25%, 50%, 75% and 100% asphaltite by weight of filler were 2.9, 3.6, 5.4 and 7.9 times greater than those of the control mixtures respectively at 300 kPa stress level. Using asphaltite as filler exhibited high performance by improving especially the resistance to moisture damage and fatigue life.

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1. Introduction

Asphalt concrete is the most commonly used material in pavement because of its superior service performance in providing driving comfort, stability, durability and water resistance. The escalating cost of materials and energy and lack of resources available have motivated highway engineers to explore new alternatives in building new roads.

There are several ways to improve the engineering properties of asphalt concrete. One way is to change the gradation and asphalt cement proportion. Stone mastic asphalt (SMA) is a typical example in this category for achieving improved mixture performance. Another way to improve the performance of mixtures is to modify the bitumen with additives. The most used additives are polymers. For the past two decades significant research has been conducted on polymer modified asphalt (PMA) mixtures. Polymers can successfully improve the performance of asphalt pavements at low, intermediate and high temperatures by increasing mixture resistance to fatigue cracking, thermal cracking and permanent deformation [1]. The most commonly used polymer for bitumen modification is styrene–butadiene–styrene (SBS) followed by other polymers such as styrene–butadiene–rubber (SBR), ethylene–vinyl–acetate (EVA), and polyethylene [2,3]. Another additive is natural asphalt to modify the base bitumen. Natural asphalts can be found in different forms, such as bitumen deposits, ‘lake asphalt’

or rock asphalt, and in different degrees of purity. Bitumen deposits occurring naturally and termed as asphaltite in general have been reported to be found approximately 82 million tons in Turkey [4]. Since asphaltite which consists of high amount of sulfur leads to air pollution when used as a heating material and also being hydrocarbon sourced, it seems better to use asphaltite in the hot mix asphalts. The most extensively utilized asphaltite is known as Uintaite. Also known as gilsonite, Uintaite contains pure natural hydrocarbon (with a purity over 99%) and 70% asphaltene. Addition of natural asphalt (Uintaite) into unmodified bitumen caused a reduction in penetration, and an increase in softening point. Besides, it brought about an increase in complex modulus and a reduction in phase angle that indicates an increased elastic response [5]. Anderson et al. [6] showed that the addition of gilsonite yields an increase in modulus. It appears that modifications with gilsonite cause an increase in asphalt binder stiffness [7].

Besides the bitumen modification, some additives are utilized directly with aggregate in the mixture to enhance the moisture resistance of mixtures, in particular. Hydrated lime and quicklime are the most commonly used solid type additives [8–10]. The literature discusses the use of fillers such as marble dust, crumb rubber, silica fume and carbon black as modifier for asphalt mixture [11–16]. The recycled glass has also been revealed to be a viable material for asphalt concrete [17]. There are a few published studies on the effect of asphaltite on hot mix asphalt. Due to very limited number of studies on this modifier, asphaltite was used in hot mix asphalt as filler in this research. The usage of asphaltite at various percentages such as 25%, 50%, 75% and 100% by weight of filler

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were investigated. The physical and mechanical properties of asphaltite modified mixtures and control mixtures were evaluated with mechanical tests such as Marshall stability, tensile strength, stiffness modulus, and indirect tensile fatigue tests.

2. Materials and sample preparation

An asphalt cement, B 160–220, obtained from Turkish Petroleum Refineries was used as binder for mixture preparation. The mixing and compaction temperatures were determined for binder by using the 170 ± 20 and 280 ± 30 cP viscosity values, respectively. The physical and rheological properties of bitumen are given in Table 1. Limestone aggregate was used for the asphalt mixtures. The properties of aggregate are given in Table 2. Limestone is known as an alkaline aggregate hence it exhibits good adhesion with bitumen [18]. A crushed coarse and fine aggregate with maximum size of 19 mm was selected for a dense graded asphalt mixture. The gradation of the aggregate mixtures is given in Table 3.

The asphaltite was supplied from asphaltite mine in Silopi region in Turkey. Asphaltite is a complex mixture consisting of compounds ranging from nonpolar aliphatic and naphthenic hydrocarbons to highly polar aromatic molecules containing heteroatoms such as oxygen, nitrogen and sulfur [19]. The asphaltite was grinded and the particles smaller than 0.075 mm were assorted to use as filler in hot mix asphalt. The proximate and elemental analyses of asphaltite are given in Table 4 [20].

An amount of limestone filler replaced with an amount of asphaltite in the aggregate gradation by preparing the mixtures. The specimens were classified into five groups. The first group was the control specimens (C). In the second group of specimens 25% limestone filler was replaced with asphaltite and was represented by F25. In the third group of specimens 50% limestone filler was replaced with asphaltite and was represented by F50. In the fourth and the last group of specimens 75% and 100% limestone filler was replaced with asphaltite and were represented by F75 and F100 respectively. Since asphaltite contains 20% bitumen fraction the final filler content of the mixtures by weight of total aggregate range as 5.7%, 5.4%, 5.1% and 4.8% for F25, F50, F75 and F100 respectively.

The mix design of the asphalt mixtures was conducted by using the standard Marshall mix design procedure with samples which had a diameter of 10.16 cm and a thickness of 6.35 cm. Marshall samples were compacted and tested by employing the following standard procedures: Bulk specific gravity (ASTM D2726), stability and flow test (ASTM D6927), and maximum theoretical specific gravity (ASTM D2041). The optimum binder contents, referred to % added B160–220, were determined to be 4.91%, 4.84%, 4.71%, 4.61%, 4.56% for control, F25, F50, F75 and F100 respectively. The specimens were compacted by using 75 blows

Table 3

Combined aggregate gradation.

Sieve size	Total cumulative passing (%)				
	C	F25	F50	F75	F100
19 mm (3/4")	100				
12.5 mm (1/2")	95				
9.5 mm (3/8")	88				
4.75 mm (# 4)	65				
2.36 mm (# 8)	39				
1.18 mm (# 16)	24				
0.600 mm (# 30)	18				
0.300 mm (# 50)	14				
0.150 mm (# 100)	10				
0.075 mm (# 200)	6	5.7	5.4	5.1	4.8

on each side of cylindrical samples for the Marshall stability and flow test, indirect tensile stiffness modulus test and indirect tensile fatigue test. As for the tensile strength test the specimens were compacted to have 6–8% air void.

3. Test methods

3.1. Marshall stability and flow test

The specimens were divided into two groups each of which are consisted 15 mixtures, and the average specific gravity of the specimens of the each group was equal. The first group of specimens was immersed in water at 60 °C for 30 min and then loaded to failure by using curved steel loading plates along with the diameter at a constant rate of compression of 51 mm/min. The second group of specimens (conditioned specimens) was placed in water bath at 60 °C for 24 h. And then the same loading was applied as described above. The stability and flow and also the ratio of stability (kN) to flow (mm), stated as the Marshall quotient (MQ), and as an indication of the stiffness of mixes were determined. It is well recognized that the MQ is a measure of the materials' resistance to shear stresses, permanent deformation and hence rutting [21]. High MQ values indicate a mix with high stiffness and with a greater ability to spread the applied load and resistance to creep deformation. The ratio of stability to flow of unconditioned and conditioned specimens was represented by MQ1 and MQ2, respectively. The retained Marshall stability (RMS) was then found by using the average stability of each group employing the following formula [22]:

$$RMS = 100(MS_{\text{cond.}}/MS_{\text{uncond.}}) \quad (1)$$

where RMS is the retained Marshall stability; $MS_{\text{cond.}}$ is the average Marshall stability for conditioned specimens (kN); and $MS_{\text{uncond.}}$ is the average Marshall stability for unconditioned specimens (kN).

3.2. Indirect tensile stiffness modulus test

Stiffness modulus of asphalt mixtures that is measured in the indirect tensile mode is one of the most popular form of stress–strain measurement used to evaluate elastic properties and consid-

Table 1

Fundamental properties of binder before and after short term aging.

Properties	Standard	Results
Penetration (0.1 mm), 100 g, 5 s	ASTM D5	190
Softening point (°C)	ASTM D36	40.9
Viscosity (cP, 135 °C)	ASTM D4402	237.5
Viscosity (cP, 165 °C)	ASTM D4402	87.5
$G^*/\sin \delta$ (kPa), 58 °C	AASHTO T5	1.08
Mixing temperature range (°C)	–	142–149
Compaction temperature range (°C)	–	127–133
Penetration index (PI)	–	0.12
<i>After RTFOT</i>		
Mass Loss (%)	ASTM D2872	0.935
Penetration (0.1 mm), 100 g, 5 s	ASTM D5	97
Retained penetration (%)	–	51
Softening point (°C)	ASTM D36	50.3
Increase in softening point (°C)	–	9.4
$G^*/\sin \delta$ (kPa), 58 °C	AASHTO T5	5.33
Penetration index (PI)	–	0.67

Table 2

Physical properties of aggregate.

Properties	Standard	Aggregate			
		Coarse	Fine	Filler	Asphaltite
Abrasion loss (%) (Los Angeles)	ASTM DC 131	28	–	–	–
Frost action (%) (with Na ₂ SO ₄)	ASTM C 88	4.5	–	–	–
Specific gravity (g/cm ³)	ASTM C127	2.684	–	–	–
Water absorption (%)	ASTM C127	1.34	–	–	–
Specific gravity (g/cm ³)	ASTM C128	–	2.699	–	–
Specific gravity (g/cm ³)	ASTM D854	–	–	2.703	1.483

Table 4

Proximate and elemental analysis of asphaltite samples [20].

	Moisture (%)	Ash (%)	Volatile matter (%)	Lower heating value (kcal/kg)	Carbon (%)	Hydrogen (%)	Sulfur (%)	Nitrogen + Oxygen (%)
Silopi asphaltite	6.14	32.53	47.21	5491	54.22	5.07	8.23	0.25

ered to be a very important performance characteristic of the pavement. It is a measure of the load-spreading ability of the bituminous layers and it controls the tensile strains at the underside of the roadbase induced by traffic. The indirect tensile stiffness modulus (ITSM) test defined by BS DD 213 (BSI 1993) is a non-destructive test. The ITSM S_m in MPa is defined as

$$S_m = L(v + 0.27)/Dt \quad (2)$$

where L is the peak value of the applied vertical load (repeated load) (N); D is the mean amplitude of the horizontal deformation obtained from five applications of the load pulse (mm); t is the mean thickness of the test specimen (mm); and v is the Poisson's ratio (assumed to be 0.35). The test was performed as deformation controlled. The universal testing machine (UTM) was used for the test. The magnitude of the applied force was adjusted by the system during the first five conditioning pulses such that the specified target peak transient diametral deformation was achieved. A value was chosen to ensure the sufficient signal amplitudes to be obtained from the transducers in order to produce consistent and accurate results. The value was selected to be 7 μ m in this test. During testing, the rise time was set at 124 ms, which is the time taken for the applied load to increase from zero to a maximum value. The load pulse application was equated to 3.0 s. The test was performed at 15 °C, 25 °C and 35 °C.

3.3. Tensile strength test

In the tensile strength test (TS), cylindrical specimens were subjected to compressive loads, which act parallel to the vertical diametral plane, by using the Marshall loading equipment. This type of loading produces a relatively uniform tensile stress, which acts perpendicular to the applied load plane, and the specimen usually fails by splitting along with the loaded plane. Based upon the maximum load at failure, the TS in kPa is calculated from the following equation:

$$TS = 2F/\pi LD \quad (3)$$

where F is the peak value of the applied vertical load (kN); L is the mean thickness of the test specimen (m); and D is the specimen diameter (m). The tensile test was used for the determination of the moisture susceptibility of asphalt concrete mixture in accordance with ASTM D 4867. The effect of asphaltite on moisture-induced damage of asphalt concrete mixtures was evaluated. Three unconditioned (dry) and three conditioned (wet) specimens were tested for each group of mixtures. Wet specimens were vacuum-saturated with distilled water so that 50–80% of their air voids were filled with water, and then they were wrapped tightly with plastic film. The specimens were then placed into a leak-proof plastic bag containing approximately 3 ml of distilled water. Afterwards wet specimens were subjected to one freeze–thaw cycle. One freeze–thaw cycle consists of freezing for 16 h at -18 °C, followed by soaking in a 60 °C water bath for 24 h. At the end of the cycle, the bag and the wrapping were removed and specimens were placed in a water bath for 1 h at 25 °C before being subjected to failure. The tensile strength of dry specimens was determined directly. Dry specimens were placed only in a water bath for 1 h at 25 °C before being subjected to failure. The tensile strength ratio (TSR) was determined with following equation:

$$TSR = 100(P_{cond.}/P_{uncond.}) \quad (4)$$

where $P_{cond.}$ is the tensile strength of the wet specimens and $P_{uncond.}$ is the tensile strength of the dry specimens.

3.4. Indirect tensile fatigue test

Fatigue is considered to be one of the most significant distress modes in pavements associated with repeated traffic loads. In this study, a constant stress indirect tensile fatigue test was conducted by applying cyclic constant loads equal to 200 kPa and 300 kPa with a 0.1-s loading followed by a 1.4-s rest period. The universal testing machine (UTM) was used for this purpose. The machine has a servo-hydraulic test system. The loading frame was housed in an environmental chamber to control temperature during the test. The desired load level, load rate and load duration were controlled by a computer. The deformation of the specimen was monitored through linear variable differential transducers (LVDTs). The LVDTs were clamped vertically on the diametrical side of the specimen. A repeated dynamic compressive load was applied to specimens across the vertical cross section along the depth of the specimen using two loading strips 12.5 mm in width. The resulting total deformation parallel to the applied force was measured. The indirect tensile fatigue test was performed according to the following procedures: The specimen was first placed in an environmental chamber before testing, for at least 6 h, in order to reach the equilibrium testing temperature (25 °C), then the specimens were positioned on the loading frame so that the two faces of the specimen were normally perpendicular to the loading strip. 200 kPa and 300 kPa loads were applied, and the slope of the accumulated deformation and the cycle number were monitored. The test was lasted until the specimen collapsed.

4. Results and discussion

4.1. 4.1. Marshall stability and flow test

The Marshall stabilities and MQ values for both conditioned and unconditioned mixtures are given in Figs. 1 and 2 respectively. The values are the average of three samples.

It is seen from Fig. 1 that the stability value of unconditioned mixtures (MS1) did not exhibit a steady arrangement with the increase of asphaltite content. However the stability of conditioned mixtures (MS2) increased with the increase of asphaltite content. The MS2 value improved approximately 30% when asphaltite alone was used as filler. It is considered that this test method is sensitive to bitumen type and bitumen content. Besides it is well known that the Marshall stability is affected by the aggregate gradation and aggregate type in the mixtures. Since all types of mixtures prepared with their own optimum bitumen content, and the used bitumen and the type of used coarse and fine aggregate, and also their gradation were the same in all types of mixtures, the stability values of unconditioned mixtures were not changed excessively. The effects of adding asphaltite as filler on Marshall stabilities of unconditioned mixtures were not observed clearly with this test method. The effect of asphaltite on MQ values is seen in Fig. 2. The MQ1 did not exhibit a steady arrangement with the increase of asphaltite content as unconditioned stability values. The values fluctuated between 5.33 and 6.11. The improvement effect of

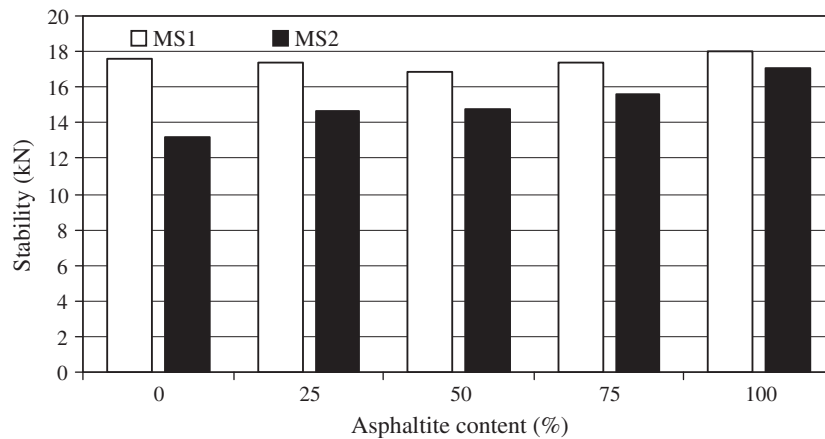


Fig. 1. Stability values of unconditioned and conditioned mixtures.

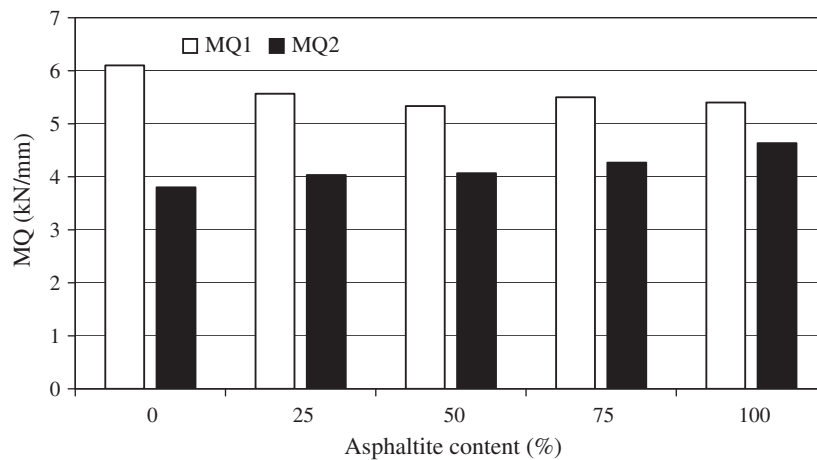


Fig. 2. MQ values of unconditioned and conditioned mixtures.

asphaltite at conditioned situation is more apparent than that of at unconditioned stage. The MQ2 values of F100 mixture increased 21% more than control mixtures. The increased MS and MQ indicates an improved potential for carrying heavy traffic loads and resistant to rutting at especially high temperature.

In Fig. 3 the relation between retained Marshall stability and asphaltite content by weight of filler are given. It is seen that the RMS values increases as asphaltite content increases. It is also seen that only the F75 and F100 seems suitable for surface coarse by providing above 90% retained Marshall stability. The improvement effects of asphaltite on RMS are apparent at 25% level, in particular. The increase in RMS slightly continues between 25% and 75% content of asphaltite. A prominent increase was observed again towards 100% asphaltite content. The RMS value of control mixture was 75%. This value reached 95.2% with a 27% increase compared to control ones for the F100 mixture. These results explain that asphaltite can resist well to water effects.

4.2. Indirect tensile stiffness modulus test

The test results of stiffness modulus are shown in Fig. 4. The presented data are the mean value of five tests for each of the three temperatures. As can be seen in this figure, the stiffness modulus values increased with the increase of asphaltite content at all temperatures. However the improvement effect of asphaltite varied from low temperatures to high temperatures. This may be attributed by further modification of bitumen 160–220 by asphaltite.

The stiffness modulus values increased regularly with the increase of asphaltite at 25 °C and 35 °C. However the increase took place exponentially at 15 °C. Especially the mixtures including 75% and 100% asphaltite by weight of filler exhibited significant increase in stiffness modulus. The F100 sample had approximately 91%, 74% and 63% higher stiffness modulus than that of the control sample at 15 °C, 25 °C and 35 °C respectively. It proves that the mixtures containing asphaltite can resist to high loads at intermediates temperatures. Moreover, the asphaltite modified mixtures showed higher stiffness modulus at higher temperatures than the control ones, and can provide with a resistance to traffic load without rutting.

4.3. Tensile strength test

The unconditioned and conditioned tensile strengths of the mixtures are given in Fig. 5. Accordingly, the TS values of both dry and wet mixtures increase with the increase of asphaltite content. The dry and wet TS values of the mixtures containing 100% asphaltite by weight of filler were greater by 44% and 95% than those of the control mixtures. Two factors might lead to a significant increase in TS value. The first factor may be that the asphaltite particles act as an adhesive agent between aggregate surface and bitumen. Hence significant increase of TS values could be attributed to the adhesive effects of asphaltite during the preparation of mixtures. Since the increase of conditioned TS values are much more greater than that of the unconditioned mixtures, the second

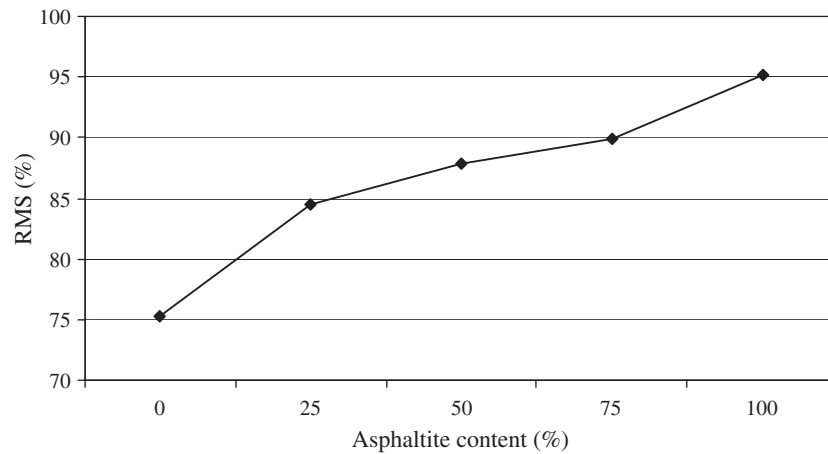


Fig. 3. Relation between retained Marshall stability and asphaltite content.

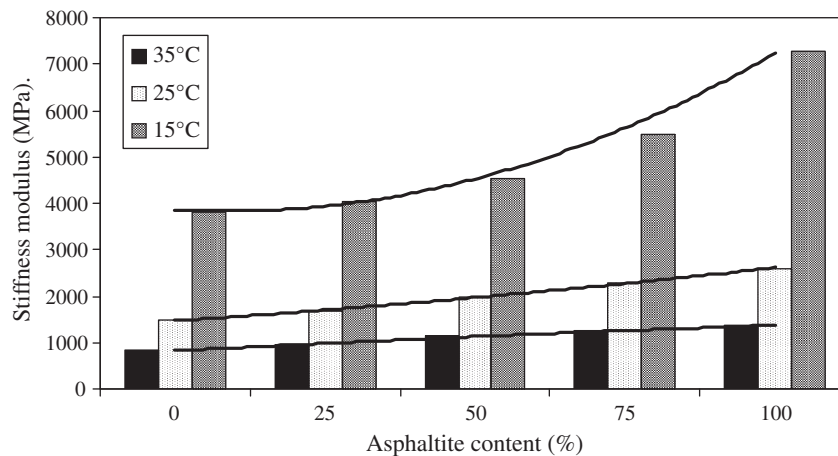


Fig. 4. Stiffness modulus of mixtures.

factor may be the hardening of asphalt by keeping 24 h at 60 °C. It is considered that the asphaltite particles get in a sticky form at this temperature by waiting for a long time. Therefore, these forms of asphaltite support improving the resistance of mixture to moisture effect. Fig. 6 shows the tensile strength ratios of the mixtures after one freeze–thaw cycle. It is seen that the TSR values increase with the increase of the asphaltite content. However only the F100

seems to be suitable for surfacing of major roads by providing above 80% TSR. TSR value increased by 10% compared to control samples through using 25% asphaltite. The increase in TSR continued slightly between the mixtures including 25% and 75% asphaltite. A prominent increase was observed again toward 100% asphaltite content. While the control mixtures lost 35% of its tensile strength after one freeze–thaw cycle, the mixtures containing

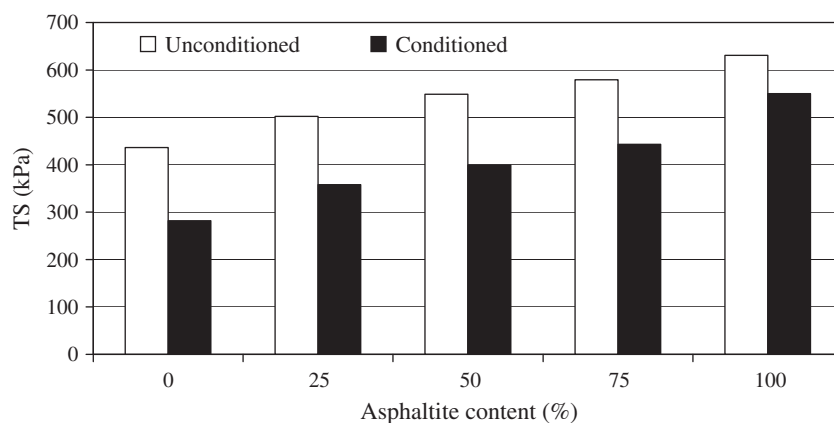


Fig. 5. Unconditioned and conditioned tensile strengths of the mixtures.

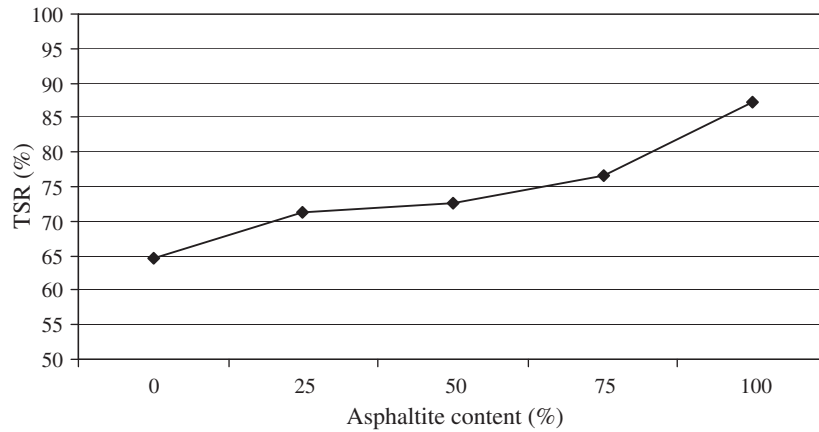


Fig. 6. Tensile strength ratios of the mixtures.

completely asphaltite as filler lost only by 13%. These results are in compliance with the retained Marshall stability test, where the specimens were kept 24 h at 60 °C.

4.4. Indirect tensile fatigue test

Based on the results of fatigue test, the number of load repetitions until the specimens entirely collapse were determined for five types of mixtures. Figs. 7 and 8 show the changes in accumulated deformation versus the number of load repetitions under 200 kPa and 300 kPa stress levels respectively. It is seen from figures that the curves have three regions. At the first region, since

the air voids were pinched in with the load repetition, the accumulated deformations increased rapidly. At the second region after losing its air voids and becoming a pressed state, the accumulated deformations of the mixture increased linearly with the load cycle. At the beginning of the third region the cracks occurred. Since the test was performed as being stress controlled, the deformations increased rapidly after the initial crack in the third region. It is seen that the initial cracks occurred when the accumulated deformations reached 2 mm and 1.5 mm under 200 kPa and 300 kPa stress levels respectively. The relation between load repetition number and asphaltite content by weight of filler are given in Fig. 9. The data presented are the mean value of three tested specimens for

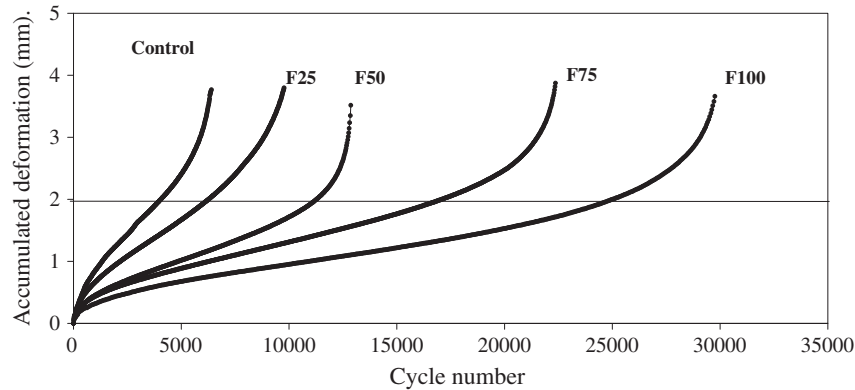


Fig. 7. Accumulated deformation versus load cycle at 200 kPa stress level.

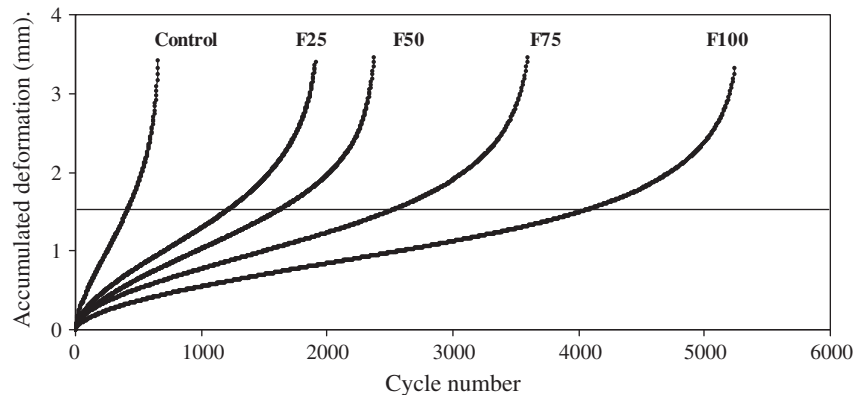


Fig. 8. Accumulated deformation versus load cycle at 300 kPa stress level.

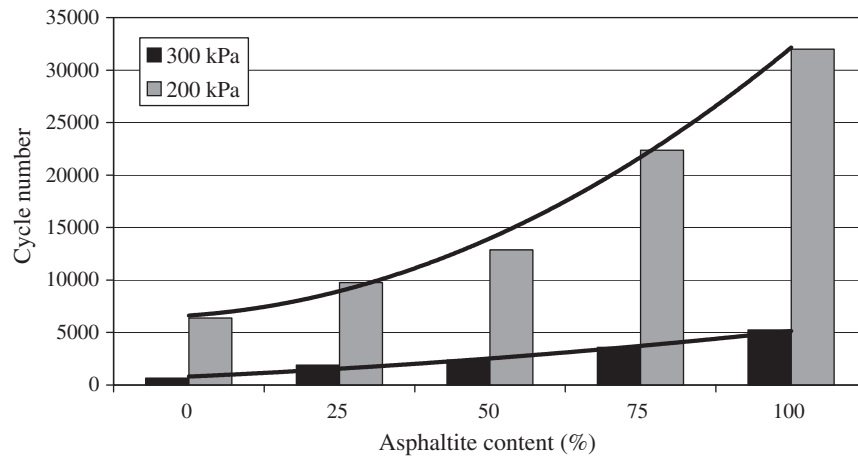


Fig. 9. Relation between load cycle and asphaltite content.

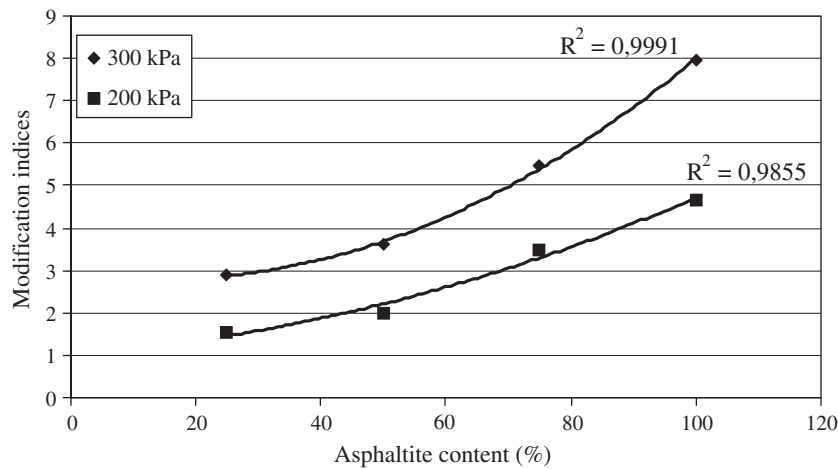


Fig. 10. Modification indices versus asphaltite content.

each of the five types of mixtures. It is obvious that the fatigue life of mixtures increase significantly with the increase of asphaltite content. The modification indices were determined by dividing the cycle number of asphaltite modified mixtures by cycle number of the control mixture and presented in Fig. 10. The cycle number led to failure of the mixtures containing 25%, 50%, 75%, 100% asphaltite by weight of filler are 2.9, 3.6, 5.4 and 7.9 times greater than that of the control mixtures respectively at 300 kPa stress level. As for the 200 kPa stress level, the improvement effects of the asphaltite are ranged as 1.5, 2.0, 3.5 and 5.0 times. The improvement effect of asphaltite on fatigue life at high stress level is greater than that of at low stress level. It was also concluded that the mixtures containing asphaltite were less influenced than the control mixtures in terms of the increase of stress level. The increase of stress level from 200 kPa to 300 kPa (an increase of 1.5 times) decreased the fatigue life of control mixtures nine times. However this downturn in the fatigue life was 5–6 times for the asphaltite modified mixtures.

5. Conclusion

The objectives of this study were to evaluate the effects of asphaltite as mineral filler in hot mix asphalt. Various laboratory tests were used to evaluate the characteristics of hot mix asphalt

with varying contents of asphaltite. Based on the laboratory test results, the following conclusions were drawn:

In the Marshall stability test, Marshall stability values of unconditioned mixtures did not exhibit a steady arrangement with the increase of asphaltite content. The effects of using asphaltite as filler on unconditioned Marshall stability was not observed clearly with this test method. However the stability of conditioned mixtures (MS2) increased with the increase of asphaltite content. The results of MQ values also exhibited similar behavior. The retained Marshall stability value result explains that asphaltite can resist well to water effects.

The indirect tensile stiffness modulus test was performed at three different temperatures. The stiffness modulus values increased regularly with the increase of asphaltite at 25 °C and 35 °C. However this increase became exponential at 15 °C. The results proves that the mixtures containing asphaltite can resist to high loads at low temperatures. Moreover, the asphaltite modified mixtures showed higher stiffness modulus at higher temperatures than the control ones, and can provide with a resistance to traffic load without rutting.

In the tensile strength test, it was determined that the dry and wet TS values of the mixtures containing 100% asphaltite by weight of filler were greater 44% and 95% than those of the control mixtures. The results showed that the tensile strength ratios increased with the asphaltite content. While the control mixtures lost 35% of

its tensile strength after one freeze–thaw cycle, the mixtures containing completely asphaltite as filler lost only by 13%.

The improvement effect of using asphaltite as filler was signposted with fatigue test. The cycle number led to failure of the mixtures containing 25%, 50%, 75%, 100% asphaltite by weight of filler were 2.9, 3.6, 5.4 and 7.9 times greater than that of the control mixtures respectively at 300 kPa stress level. As for the 200 kPa stress level the improvement effects of the asphaltite are ranged as 1.5, 2.0, 3.5 and 5.0 times. It was also concluded that the mixtures containing asphaltite were less influenced than the control mixtures with the increase of stress level.

It was concluded through the laboratory test results that using of asphaltite as filler in hot mix asphalt exhibited high performance by improving especially the resistance to moisture damage and fatigue life. This study indicated that the asphaltite, which induces air pollution when used as a heating material, could be an alternative material for producing the hot mix asphalt.

References

- [1] Khattak MJ, Baladi GY. Fatigue and permanent deformation models for polymer-modified asphalt mixtures. In: Proceedings of the 80th transportation research board annual meeting, Washington DC; 2001.
- [2] Lu X, Isacsson U. Rheological characterization of styrene–butadiene–styrene copolymer modified bitumens. *Constr Build Mater* 1997;1:23–32.
- [3] Yildirim Y. Polymer modified asphalt binders. *Constr Build Mater* 2007;21(1):66–72.
- [4] Soyhan HS. Sustainable energy production and consumption in Turkey: a review. *Renew Sust Energ Rev* 2009;13:1350–60.
- [5] Widyatmoko I, Elliott R. Characteristics of elastomeric and plastomeric binders in contact with natural asphalts. *Constr Build Mater* 2008;22:239–49.
- [6] Anderson DA, Maurer D, Ramirez T, Christensen DW, Marasteanu MO, Mehta Y. Field performance of modified asphalt binders evaluated with superpave test methods: I-80 test project. *Trans Res Rec* 1999;1661:60–8.
- [7] Aflaki S, Tabatabaee N. Proposals for modification of Iranian bitumen to meet the climatic requirements of Iran. *Constr Build Mater* 2009;23:2141–50.
- [8] Little DN, Epps JA. Hydrated lime in hot mix asphalt. Presentation manual. FHWA-HI-93-032. FHWA, AASHTO, and National Lime Association (NLA); 1993.
- [9] Kok BV, Yilmaz M. The effects of using lime and styrene–butadiene–styrene on moisture sensitivity resistance of hot mix asphalt. *Constr Build Mater* 2009;23:1999–2006.
- [10] Kiggundu BM, Roberts FL. The success/failure of methods used to predict the stripping potential in the performance of bituminous pavement mixtures. Auburn University: National Center for Asphalt Technology; 1988.
- [11] Karasahin M, Terzi S. Evaluation of marble waste dust in the mixture of asphalt concrete. *Constr Build Mater* 2007;21(3):616–20.
- [12] Akbulut H, Guler C. Use of aggregates produced from marble quarry waste in asphalt pavements. *Build Environ* 2007;42:1921–30.
- [13] Chui-Te C. Use of ground tire rubber in asphalt pavements: field trial and evaluation in Taiwan. *Conserv Recycling* 2008;52:522–32.
- [14] Fritschy G, Papirer E. Dynamic-mechanical properties of a bitumen–silica composite: I. Relation with filler content and bitumen–silica interfacial area. *Rheol Acta* 1979;18:749–55.
- [15] Jianying Y, Peiliang C, Shaopeng W. Investigation of the properties of asphalt and its mixtures containing flame retardant modifier. *Constr Build Mater* 2009;23:2277–82.
- [16] Yamaguchi K, Sasaki I, Nishizaki I. Effects of film thickness, wavelength and carbon black on photodegradation of asphalt. *J Jpn Petrol Ins* 2005;48(3):150–5.
- [17] Nan S, Chen JS. Engineering properties of asphalt concrete made with recycled glass. *Conserv Recycling* 2002;35:259–74.
- [18] Huang SC, Robertson RE, Branthaver JF. Physico-chemical characterization of asphalt–aggregate interactions under the influence of freeze–thaw cycles. TRB annual meeting; 2003.
- [19] Bukka K, Miller JD, Oblad AG. Fractionation and characterization of Utah tar sand bitumens: influence of chemical composition on bitumen viscosity. *Energy Fuel* 1991;5:333–40.
- [20] Sezer M, Bilgesu AY, Karaduman A. Flash pyrolysis of Silopi asphaltite in a free-fall reactor under vacuum. *J Anal Appl Pyrolysis* 2008;82:89–95.
- [21] Zoorob SE, Suparna LB. Laboratory design and investigation of the properties of continuously graded asphaltic concrete containing recycled plastics aggregate replacement (plastiphalt). *Cem Concr Compos* 2000;22:233–42.
- [22] Defence works: functional standards, Marshall Asphalt for airfield pavement works, Specification 013; August 2005.