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Investigation of the Properties of Warm Mix Asphalt Involving Organic Additive

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Abstract

Demand for sustainable pavements increases day by day in asphalt paving industry. Warm Mix Asphalt (WMA) technology has begun to be an interesting topic for researchers owing to sustainability and environmental issues. Within the scope of this study, the effect of an organic WMA additive was evaluated in terms of mixture characteristics and performance. The fundamental and rheological properties of bitumen samples involving organic WMA additive were determined by conventional bitumen tests and dynamic shear rheometer (DSR). Mixtures modified with organic WMA additives were produced according to Marshall mix design method and the optimum bitumen content of the samples were determined. Following the determination of optimum bitumen content, the effect of the organic WMA additive was investigated in terms of indirect tensile stiffness modulus, fatigue and creep behaviour. Hamburg wheel tracking device was also applied to evaluate the permanent deformation characteristics of WMA mixtures in comparison to Hot Mix Asphalt (HMA) mixtures. The results appraised the effect of the organic WMA additive on rheological and performance characteristics of bituminous mixtures.

Keywords: Warm mix asphalt, Organic additive, Mixture characteristics, Dynamic shear rheometer, Fatigue behaviour, Hamburg wheel tracking device.

Organik Katkı İçeren Ilık Karışım Asfaltın Özelliklerinin İncelenmesi

Özet

Asfalt kaplama endüstrisinde sürdürülebilir kaplama gereksinimi her geçen gün artmaktadır. Ilık Karışım Asfalt (WMA) teknolojisi sürdürülebilirlik ve çevre sorunları nedeniyle araştırmacılar için ilgi çekici bir konu olmaya başlamıştır. Bu çalışma kapsamında, organik bir WMA katkı maddesinin karışım özellikleri ve performansı üzerindeki etkisi değerlendirilmiştir. Organik WMA katkısı içeren bitüm numunelerinin temel ve reolojik özellikleri, geleneksel bitüm deneyleri ve dinamik kayma reometresi (DSR) deneyi ile belirlenmiştir. Organik WMA katkı maddesi ile modifiye edilmiş karışımların tasarımı Marshall karışım tasarımı yöntemine göre yapılmış ve karışımın optimum bitüm içeriği tespit edilmiştir. Optimum bitüm içeriği belirlendikten sonra, indirekt çekme rijitlik modülü, yorulma ve sünme davranışı açısından organik WMA katkı maddesinin etkisi araştırılmıştır. Ayrıca WMA karışımlarının kalıcı deformasyon özelliklerini Sıcak Karışım Asfalt (HMA) ile kıyaslayabilmek amacıyla Hamburg tekerlek izi deneyi de uygulanmıştır. Sonuçlar, organik WMA katkısının bitümlü karışımların reolojik ve performans özellikleri üzerinde etkili olduğunu göstermiştir.

Anahtar Kelimeler: Ilık karışım asfalt, Organik katkı maddesi, Karışım özellikleri, Dinamik kayma reometresi, Yorulma davranışı, Hamburg tekerlek izi cihazı.

1. Introduction

Most of the field pavement practices around the world consist of conventional hot mix asphalt (HMA). For the last decade, implementing of warm mix asphalt (WMA) technologies has gained popularity in Europe and in some other countries as well as in the USA. The goal of WMA technologies is to obtain required strength and durability which is equivalent to or even better than HMA pavements [1]. The use of WMA technologies offers many benefits to asphalt industries. Many studies have common sight about the various advantages of the utilization of WMA technologies. These advantages are all originated from the major feature of WMA additives which is reducing the viscosity of the bitumen [2]. This reduction results in increasing workability and ease of use, ecological benefits due to less emissions and reduction in costs due to less energy use. In terms of workability, the reduced viscosity helps the aggregates to be coated more easily [3, 4]. When discussing about environmental benefits, there are serious worries about the greenhouse gases emissions in HMA pavement applications. Due to lower application temperatures of WMA mixes, the emission of carbon dioxide (CO2) and other so called greenhouse gases are lowered in comparison with HMA mixes [5]. Besides, the evaporation of less heavy components of bitumen occurs less than conventional applications. This causes less odours in asphalt plants, therefore provides more pleasant working conditions. Builders comments also indicate that the fumes are rather less in WMA production in comparison with HMA production [6]. The fuel consumption of WMA technologies is rather less than conventional HMA mixtures. Energy consumption for WMA production has been reported as 60–80% of HMA production [4]. Some studies have also reported the range of 20–35% of savings in burner fuel with use of WMA technologies [5]. In asphalt industry, a common way of achieving lower application temperatures in order to produce WMA is the utilization of WMA additives. All of the current WMA additives facilitate lowering of production temperature by either lowering the viscosity and/or expanding the volume of the bitumen at a given temperature [7, 8]. There are many kinds of WMA additives, these additives are categorized as chemical, zeolite or organic additive etc. Organic WMA additives those are the most common as aforementioned, WMA additives used to improve workability by reducing the viscosity of bitumen [9]. By lowering the viscosity, asphalt can be produced at lower temperatures compared to conventional HMA. Organic WMA additives are reported as resistance improvers against permanent deformation by composing crystallized structures after cooling [10].

In this research, WMA mixture has been prepared with an optimum rate of organic WMA additive that is based on the recommendation of manufacturers. The mechanical performances of the samples were evaluated by Marshall stability test. Following, WMA samples involving organic WMA additive; indirect tensile stiffness modulus (ITSM) and fatigue behaviour of WMA were analyzed and compared with control specimens (HMA). Hamburg wheel tracking device was also used to determine the rutting performance of WMA mixture.

2. Material and Method

In this study, 50/70 penetration grade base bitumen provided from Aliağa/Izmir petroleum refinery was used. In order to characterize the properties of the base bitumen, conventional tests such as: penetration test, softening point test, Rolling Thin Film Oven Test (RTFOT) and etc. were conducted. These tests were performed in conformity with the relevant standards. Results are presented in Table 1.

Table 1. Properties Of Base Bitumen

Test	Specifications	Results	Limits
Penetration (25 °C; 0.1 mm)	ASTM D5/D5M-13 TS EN 1426	55	50-70
Softening point (°C)	ASTM D36/D36M-12 TS EN 1427	49	46-54
Viscosity at (135 °C)-Pa.s	ASTM D4402/D4402M-13	412.5	-
Viscosity at (165 °C)-Pa.s	ASTM D1754/D1754M-09 TS EN 12607-2	-	-
Change of mass (%)	-	0.04	0.5(max.)
Retained penetration after RTFO (%)	ASTM D5/D5M-13 TS EN 1426	25	-
Softening point rise after RTFO (°C)	ASTM D36/D36M-12 TS EN 1427	54	48 (min)
Specific gravity	ASTM D70-09e1 TS EN 15326	1.03	-
Flash point (°C))	ASTM D92-12b TS 123 EN 22592	260	230 (min)

The aggregates used in this study consist of a mix of basalt and limestone aggregates provided from Dere Madencilik Inc. quarry located in Belkahve/Izmir. The mix gradation of basalt and limestone was intentionally chosen to provide desired performance in conformity with Turkish specifications concerning the Type 1 wearing course. Basalt plays the role of strengthening constituent as coarse aggregate while limestone participates in the fine aggregate framework. Table 2 presents the final gradation chosen for basalt–limestone aggregate mixture. The properties of the aggregate were investigated by several tests such as specific gravity, Los Angeles abrasion resistance, sodium sulphate soundness, fine aggregate angularity and flat and elongated particles. Test results conducted on both aggregate types are presented in Table 3.

Table 2. Gradation For Basalt–Limestone Aggregate Mixture

Test	19 – 12,5 mm Basalt	12,5 – 5 mm Basalt	5 – 0 mm Limestone	Combined Grad. (%)	Spec. Limits
Mix.(%)	15	45	40		
(3/4)″	100	100	100	100	100
(1/2)″	35.7	100	100	90.5	83-100
(3/8)″	2.5	89	100	80.5	70-90
No.4	0.4	16	100	47.3	40-55
No.10	0.3	1.2	81	33	25-38
No.40	0.2	0.7	33	13.5	10-20
No.80	0.15	0.4	22	9	6-15
No.200	0.10	0.2	13	5.3	4-10

Table 3. The Properties Of Both Basalt And Limestone

Test	Specifications	Results		Spec. Limits
		Limestone	Basalt	
Specific Gravity (Coarse Agg.)	ASTM C127-12			
Bulk		2.686	2.666	-
SSD		2.701	2.810	-
Apparent		2.727	2.706	-
Specific Gravity (Fine Agg.)	ASTM C128-12			
Bulk		2.687	2.652	-
SSD		2.703	2.770	-
Apparent		2.732	2.688	-
Specific Gravity (Filler)		2.725	2.731	-
Los Angeles Abrasion (%)	ASTM C131-06 TS EN 1097-2	24.4	14.2	maks. 45 maks. 27
Flat and Elongated Particles (%)	ASTM D4791-10 TS EN 933-3	7.5	5.5	maks 10 maks. 25
Sodium Sulphate Soundness (%)	ASTM C88-13			maks. 10-20
Fine Aggregate Angularity	ASTM C1252-06	47.85	58.1	min. 40

Sasobit® is an organic WMA additive which is product of Sasol Wax Inc. It is a long-chain aliphatic polymethlene hydrocarbon produced from the Fischer-Tropsch (FT) chemical process with a melting temperature of 120°C. The longer chains help keep the wax in solution, which reduces bitumen viscosity at typical asphalt production and compaction temperatures. Based on the literature, dosages for organic additive ranged from 1.0% to 4.0% by weight of the bitumen [11–13]. In this research, the organic additive content was chosen as 3.0% based on the past research [14]. Organic additive added to the virgin bitumen at 120°C and mixed by using the high shear mixer for 10 minutes.

2.1. Test methods

2.1.1. Conventional bitumen tests

The base bitumen and the bitumen sample containing organic additive were subjected to the following conventional bitumen tests; penetration, ring and ball softening point, thin film oven test (TFOT), penetration and softening point after TFOT as well as the storage stability test determined by the difference in softening point test results taken from the top and bottom of the tube (ASTM D5-06 2006; ASTM D36-95 2000; ASTM D 1754-97 2002) [15–17]. In addition, the temperature susceptibility of the bitumen samples has been calculated in terms of penetration index (PI) using the results obtained from penetration and softening point tests [18].

The viscosity defined as resistance of a fluid to flow is significant since it affects the workability of the bitumen [19]. Brookfield viscometer was employed to inspect the mixing and compaction temperatures of the mixtures in according to ASTM D4402-06 [20]. The test was performed at 135°C and 165°C and the temperatures corresponding to bitumen viscosities 170±20 mPa.s and 280±30 mPa.s were chosen as mixing and compaction temperatures respectively.

2.1.2. Mechanical properties

The effect of organic WMA additive on the mechanical properties of WMA has been determined by Marshall mix design method (ASTM D3549) in terms of stability, flow and air void content as well as by indirect tensile stiffness modulus test and indirect tensile fatigue test [21-24]. The tests were conducted on WMA samples at recommended contents and on HMA as control samples. Asphalt concrete specimens were prepared with a compaction effort of 75 blows simulating heavy traffic loading conditions. The ITSM test is a non-destructive test that is used to evaluate the relative quality of materials and study the effect of temperature and loading rate. The ITSM Sm in MPa is defined as below [23];

$$Sm = F(R + 0.27)/LH \qquad (1)$$

Where F is the peak value of the applied vertical load (repeated load, N), H is the mean amplitude of the horizontal deformation (mm) obtained from five applications of the load pulse, L is the mean thickness of the test specimen (mm), and R is the Poisson’s ratio (assumed as 0.35). The test was performed by way of a universal testing machine (UTM) in deformation-controlled mode. 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 obtained. An appropriate value was chosen to ensure that sufficiently high signal amplitudes were obtained from the transducers which would produce consistent and accurate results. Accordingly, this value was selected as 5 mm for this test. The rise time, which is measured from the origination of load pulse and denotes the duration of the applied load rising from zero to the maximum value, was set at 124 ms. The load pulse application was adjusted to 3.0 s. ITSM tests were conducted at three different temperatures (20 oC, 25 oC and 30 oC).

The indirect tensile fatigue test is one of the constant stress test that characterizes the fatigue behaviour of the mixture [25]. In this study, the fatigue test was performed in a controlled stress mode based on BS DD ABF standard [24]. The UTM was also used for this purpose. 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 onto the diametrical side of the specimen. A repeated dynamic compressive load at 350 kPa was applied to specimens at 20oC, 25oC and 30oC test temperatures, across the vertical cross-section along the depth of the specimen using two loading strips 12.5 mm in width. Finally, the resulting total deformation corresponding to the applied force was measured.

2.1.3. Rheological properties

The DSR test was performed on WMA samples by using a Bohlin Gemini II DSR rheometer to evaluate their rheological characterization. The test was performed under controlled stress loading conditions using low (0.01 Hz) and high (10 Hz) frequency sweeps at temperature between 30 oC and 80 oC (for every 10 oC). The stress amplitude for all the tests was confined within the linear visco-elastic response of the bitumen.

2.1.4. Rutting test

The loss of pavement serviceability is a common result from rutting which is defined as the formation of the longitudinal depressions under the wheel paths caused by the progressive movement of materials under traffic loading in the asphalt pavement layers [26]. The Hamburg wheel tracking device is designed to evaluate the rutting characteristics of bituminous mixtures by dint of aggregate structure, bitumen properties, moisture susceptibility and adhesion between bitumen and aggregates. The test is carefully contemplated to simulate bearing capacity of pavement under actual wheel tracks.

The working principle is to roll a steel wheel with a specified diameter over a bituminous mixture specimen with a standard thickness for a specified number of wheel passes. The test measures the depth of rut after the specified number of passes is reached. Various organizations may define their own specifications with different testing conditions such as specimen dimensions, wheel diameter, rolling length, applied load and temperature. Within this context, there are many devices designed to carry out the task under various conditions.

The test device used within the scope of this study, was an electronically powered device which rolls a steel wheel (capable of using rubber wheel) with a diameter of 203 mm and width of 50 mm over a well compacted specimen with dimensions of 430×280×50 mm. The device is capable of making about 50 passes in minute over the specimen's surface by rolling length of 230 mm. The applied load was chosen as 710 N by default as per EN 12697-22 standard test method [27]. Prior to compaction of the specimens, HMA and WMA mixtures were carefully mixed at their pre-defined mixing temperatures using a mixer capable of mixing adequate amount of materials at desired temperature. The Hamburg wheel tracking device comes with a roller compactor in order to compact mixtures within standard molds to fit in wheel tracking device frames. The roller compactor also makes it convenient to prepare specimens with desired thickness (50 mm) with specified air voids (4%). The amount of loose mix to reach the desired compacted bulk specific gravity corresponding to 4% air voids considering mold dimensions was calculated and poured into compaction molds. After cooling the specimens at room temperature, the specimens were subjected to 30.000 passes of wheel tracks. In this study, two specimens of HMA and WMA were prepared and tested for right and left wheels. The rut depth was measured and recorded for right and left wheels simultaneously by an electronic system at every 5.000 passes while the test was running.

3. Results and Discussion

3.1. Conventional test results

The conventional properties of the bitumen prepared with organic additive are presented in Table 4. As depicted in Table 4, the addition of the organic WMA additive decreased the penetration values and increases the softening point values.

As seen in Table 4, WMA sample exhibits higher penetration index values (which is an indicator of reduced temperature susceptibility) compared to base bitumen. Asphalt mixtures containing bitumen with higher PI are more resistant to low temperature cracking as well as permanent deformation [28]. Storage stability test indicate that, the bitumen samples with WMA additive is much more storage stable compared to HMA.

As depicted in Table 4, the additive reduce the viscosity of bitumen which indicates that, WMA additives increase the workability and make relatively reductions for mixing and compaction temperatures. The viscosity of results related to WMA additive 135°C and 165°C are drawn at semi logarithmic figure and the temperature corresponds to compaction and mixing range is also summarized in Table 5. Based on the Table 5, it can be seen that, the addition of organic WMA additive reduced the mixing and compaction temperature between 10-15°C.

Table 4. Conventional Properties Of Base And Organic Wma Modified Bitumen

Test	Base bitumen	Bitumen including Organic WMA Additive
Penetration (0.1mm)	55	37
Softening point (°C))	49.1	69.3
Viscosity at (135 °C) (mPa.s)	412.5	287.5
Viscosity at (165 °C)- (mPa.s)	137.5	75.0
Loss of mass (%)	0.04	0.07
Retained penetration (after TFOT (%)	75	87
Softening point rise after (afterTFOT (°C)	5.0	4.0
Pen. In	-1.20	1.95
Storage Stability	0	1.6

Table 5. Mixing And Compaction Temperatures

Additive Content (%)	Mixing Temperature Range(°C)	Compaction Temperature (°C)
0	156-163	143-149
3	144-149	134-138

3.2. Results of mechanicalpProperties

In this study, the optimum bitumen content related to HMA mixture as well as WMA mixture containing organic WMA additive were determined by the Marshall mix design method, retrieved directly as the bitumen content corresponding to 4% air voids on content–air voids graphic based on second degree polynomial trend lines. The optimum bitumen content for HMA mixture and WMA mixture containing organic WMA additive were determined as 4.76%, and 4.25% respectively. The ITSM values at 20°C, 25°C and 30°C temperatures for HMA and WMA mixtures containing organic WMA additive are shown in Fig. 1. As depicted in Fig. 1, the ITSM values of WMA are higher than HMA mixtures at all tested temperatures. The ITSM values of HMA mixtures and WMA mixtures containing Organic WMA additive have significantly decreased by increase in temperature.

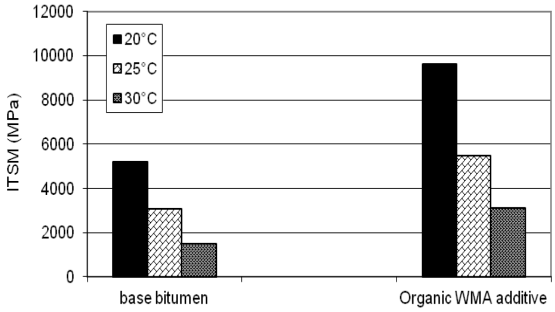

Figure 1. ITSM values of HMA WMA mixtures including organic WMA additive

The variation of load cycle numbers by temperature change is given in semi-logarithmic graphs in Fig. 2. As presented in Fig. 3, the load cycle numbers which caused the specimens to be cracked declined considerably as the temperature increased.

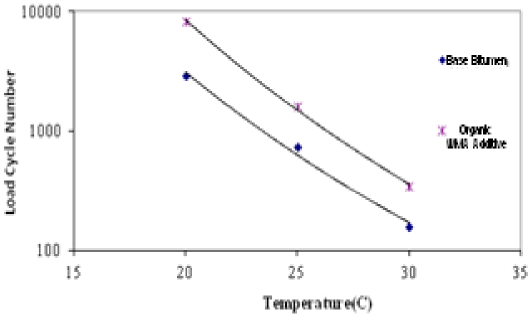

Figure 2. Variation of load cycle numbers by temperature change

The deformation of the specimens was monitored through linear variable–differential transducers (LVDTs) during the indirect tensile fatigue test. The graphs for the load cycle number corresponding permanent deformation are given in Fig. 3 for HMA and WMA mixtures at 20°C temperature. As shown in Fig. 3, HMA and WMA mixtures were cracked at approximate values of 4.3 mm, 4 mm deformation strains respectively. The specimens prepared with organic WMA additive could withstand higher load cycles and have cracked at lower deformation strains.

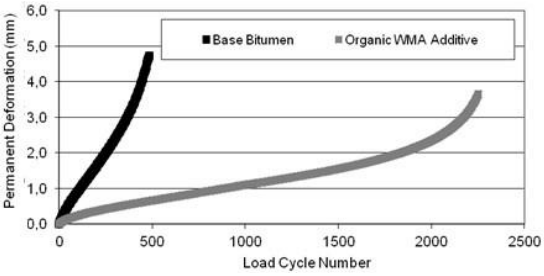

Figure 3. Permanent deformations corresponding load cycle numbers

3.3. Results of rheological properties

The variation of complex modulus (G*) of the base bitumen and the bitumen samples involving variable content of organic WMA additive at low (0.01 Hz) and high frequency level (10 Hz) and at six different temperatures are presented in Figs. 4a and 4b. As depicted in Figs. 4a-4b complex modulus increases by the decrease of temperature. An increment in G* indicates higher elastic part, thus an improved elastic behaviour. Besides, G* increases with increase in frequency. This is due to the rheological behaviour of the bitumen samples since bitumen under shorter loading times (high frequency level) exhibit elastic behaviour. G* values of the samples involving organic WMA additive are greater than G* of base bitumen for all temperatures and frequencies as seen in Figs. 4a and 4b.

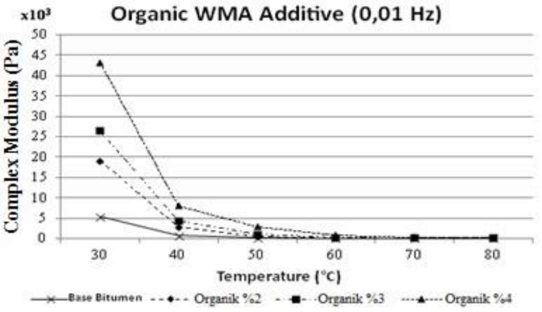

Figure 4a. Complex Modulus of organic WMA additive at 0.01 Hz.

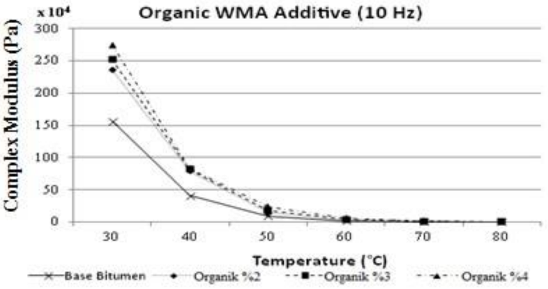

Figure 4b. Complex Modulus of organic WMA additive at 10 Hz.

3.4. Rutting test results

The Hamburg wheel tracking test was performed in accordance with EN 12697-22 standard [27]. The rut depths at 50°C are presented in Figure 5. Results are given as percent values indicating the ratio of actual rut depth over the total thickness of tested specimen (50 mm). The real rut depths (mm) are obtainable by halving the percent values. The rut depths at 50°C of HMA and WMA mixtures involving organic WMA additive were determined at each 5.000 passes initiating at 5.000 and ending at 30.000.

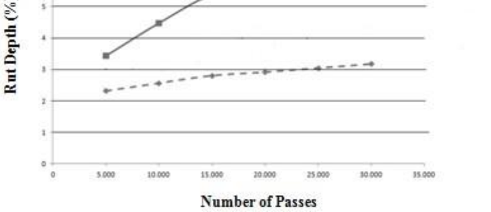

Figure 5. The rut depth % values corresponding number of passes for HMA and WMA mixtures including Organic WMA Additive

As expected the rut depth values typically increased with increase in the number of passes. Based on each number of passes, WMA mixture involving organic additive performed better than HMA mixture in terms of rut depth.

4. Conclusion

Lowering mixing and compaction temperatures and consequently the reduction of energy costs as well as emissions are the dominant advantages of utilization of WMA technologies. The utilization of organic WMA additive helps in the reduction of viscosity values which in turn reduces the mixing and compaction temperatures.

The results obtained from Marshall design demonstrated that the optimum bitumen content decreases by WMA additive. This reduction can be described as an advantage of using organic WMA additive in terms of initial cost.

ITSM values regarding HMA mixture and WMA mixture showed that the utilization of organic WMA additive increases the stiffness of mixtures. The ITSM values of all mixtures tested within the scope of this study significantly decreased by increase in temperature. As well as PI values of bitumen containing organic additive exhibited that the use of WMA additive potentially improves the temperature susceptibility.

When evaluating the load cycle numbers which caused the specimens to be cracked, WMA additive improves the repetitive loading strength of bituminous mixtures. The load cycle numbers of all mixtures significantly decrease by increase in temperature. Taking into consideration the deformation strains, WMA mixture exhibits better performance under constant loading cycles. The utilization of organic WMA additive improves the ability of asphalt pavements against permanent deformation and increases the rigidity of bituminous mixtures. The formation of crack in lower deformation levels as a result of repetitive loading is an indicator for brittle susceptibility level of a specimen.

Detailed investigation performed by DSR test at low and high frequency level and at different temperatures indicated that, the complex modulus value increases with increase in frequency and decreasing temperature. Increment in G* is attributed to improved elastic behaviour of the sample.

In the light of findings from rutting test, it is possible to consider that the organic WMA additive improves resistance to rutting characteristics of bituminous mixtures. Organic WMA additive has structural modification effects on bituminous mixtures.

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