Permanent deformation characteristics of warm mix asphalt

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ABSTRACT

Warm Mix Asphalt (WMA) is a technology that allows lowering the production and paving temperature compared to Hot Mix Asphalt (HMA). The reduction of temperature enables various benefits over asphalt mixtures such as decreasing greenhouse gas emissions, lowering energy consumption, fuel cost saving, improved workability and easy compaction. Besides, WMA technology gives an option to use Recycled Asphalt Pavement (RAP) that provides a very economic method and eco-friendly pavements.
The objective of this study was to evaluate the utilization of organic and chemical WMA additives with different percentages of RAP. Following the determination of optimum RAP contents corresponding to each WMA additive Hamburg Wheel Tracking Test is performed to obtain the permanent deformation characteristics of mixtures containing optimum RAP contents.

Keywords: Additives, Asphalt, Permanent Deformation, Reclaimed asphalt pavement (RAP) Recycling, Warm Asphalt Mixture

1. INTRODUCTION

During the last decade, the implementation and development of Recycled Asphalt Pavements (RAP) has been discussed considerably. Recent studies seem to be searching for a solution in order to reduce crude oil consumption and accordingly bitumen, an inseparable component of asphalt cement which is itself a derivative product of crude oil [1]. From a global point of view in line with commissioning of more sustainable technologies, the current recycling developments have been found secured and economically rational [2, 3]. The high cost associated with the petroleum and raw material extraction, has justified scientists to search for new materials with the ability of combining durability and performance at low cost [4]. The use of RAP provides an economic method of construction asphalt (cold recycled or hot mix asphalt (HMA)) pavements [5]. RAP contains both aggregates and bitumen, and hence its use saves natural resources, money as well as it is known as a sustainable technology which aims to implement recycled materials [6]. The rehabilitation of pavements by use of recycling technologies has been found eligible over the last decades. Considering the continuous growth of data gained from experimental studies together with laboratory and field performance analyzes, it can be anticipated that recycling technologies will go on to be the most desirable rehabilitation technology [7]. The choice of rehabilitation technique should be based on energy conservation, economic consideration, engineering consideration, environmental effects.
In last decades, ecological issues have been the most important points to be taken into account in transportation including road construction. Although HMA is widely used in road construction over the world, recent studies seek for alternative technologies which can be applied at lower temperatures. Most European countries have started to use these kinds of new technologies generally called Warm Mix Asphalt (WMA) [8]. The objective is to reach better or even equal referenced stability and durability which is reached by use of HMA [9].
The use of additives as modifying agents within bitumen has been found effective to reduce application temperatures. The current WMA additives implement two major principles to perform the mentioned task. The first principle is to reduce bitumen viscosity in order to improve workability, and the second one is to expand bitumen volume helping the aggregates coated by bitumen at lower temperatures [10, 11]. This fact results in facilitating the coating aggregates by bitumen at lower temperatures around 150˚C in comparison to conventional HMA applications [12].
Besides lowering of application temperatures, WMA technologies also facilitate the utilization of RAP materials compared to conventional HMA applications. As aforementioned, the lower viscosity and accordingly lower application temperatures can be possible by use of WMA technologies [5]. O'Sullivan and Wall reported that the use of RAP materials within WMA mixtures lowering the emission of greenhouse gases and accordingly causing less harmful effect to the environment [12]. Mallick et al. showed that it is possible the product WMA mixtures by using RAP materials [13].
Organic additives are used to improve bitumen flow by reducing the viscosity of bitumen [14]. By lowering the viscosity, asphalt can be produced at lower temperatures compared to conventional HMA. The organic WMA additives are reported as resistance improvers against permanent deformation by composing crystallized structures after cooling [15]. Besides, there are various chemical additives objective to particular products at the market. Generally chemical additives are made up of emulsifying agents, plasticizers and polymers which all help for the enhancement of workability, adhesion, and compaction. Chemical additives are also utilized so as to process RAP materials within bitumen at lower application temperatures. The effective content of chemical additive used within the WMA mixtures is defined by the suggestion of manufacturer and based on literature review [16–19].
In this research, RAP has been used (at the contents of 10–50%) within HMA and WMA mixtures containing WMA additives at recommended contents of manufacturers (organic additive at a dosage of 3% and chemical additive at a dosage of 2% by weight of the bitumen). The mechanical performances of the samples were evaluated by Marshall stability test. Following the determination of optimum RAP content of each mixture including two types of WMA additives, Hamburg wheel tracking device at 50**°C** was used to compare the rutting properties of various mixtures containing optimum RAP content.

2. EXPERIMENTAL

2.1. Materials

50/70 penetration grade base bitumen was obtained from Izmir petroleum refinery of the TUPRAS. In order to characterize the properties of the base bitumen, conventional test such as: penetration, softening point, thin film oven test (TFOT), penetration and softening point after TFOT, etc. were performed (ASTM D5-06 2006; ASTM D36-95 2000; ASTM D 1754-97 2002) [20–22]. These tests were conducted in conformity with the relevant test methods that are presented in Table 1.
The asphalt mixtures were produced with limestone aggregates that were procured from Dere Group/Izmir quarry. In order to find out the properties of the limestone aggregate used in this study, sieve analysis, specific gravity, Los Angeles abrasion resistance test, sodium sulfate soundness test, fine aggregate angularity test, and flat and elongated particles tests were conducted on limestone aggregates (ASTM C136 2008; ASTM C127 2012; ASTM C128 2012; ASTM C131 2006; ASTM C88 2005; ASTM C1252 1998; ASTM D4791 2010) [23-29].

Table 1: Properties of the base bitumen.

Test	Specification	Results	Specification Limits
Penetration (25ºC; 0.1 mm)	ASTM D5 EN 1426	55	50-70
Softening Point (ºC)	ASTM D36 EN 1427	49.1	46-54
Viscosity at (135ºC), Pa.s	ASTM D4402	0.413	-
Thin Film Oven Test (TFOT); (163ºC; 5 hr)	ASTM D1754 EN 12607-1		
Change of mass (%)		0.04	0.5 (max)
Retained penetration after TFOT (%)	ASTM D5 EN 1426	75	-
Softening Point difference after TFOT (ºC)	ASTM D36 EN 1427	5	7 (max)
Ductility (25ºC), cm	ASTM D113	100	-
Specific Gravity	ASTM D70	1.030	-
Flash Point (ºC)	ASTM D92 EN 22592	260+	230 (min)

Table 2: The properties of limestone aggregates.

Test	Specification	Grading Passing (%)	Specification Limits
Sieve Size/No.	ASTM C 136		
¾”		100	100
½”		92	83–100
3/8’’		73	70–90
No.4		44,2	40–55
No.10		31	25–38
No.40		12	10–20
No.80		8	6–15
No.200		5.3	4–10
Specific Gravity (Coarse Agg.)	ASTM C 127		
Bulk		2.704	–
SSD		2.717	–
Apparent		2.741	–
Specific Gravity (Fine Agg.)	ASTM C 128		
Bulk		2.691	–
SSD		2.709	–
Apparent		2.739	–
Specific Gravity (Filler)		2.732	–
Los Angeles Abrasion (%)	ASTM C 131	22.6	Max. 30
Flat and Elongated Particles (%)	ASTM D 4791	7.5	Max. 10
Sodium Sulfate Soundness (%)	ASTM C 88	1.47	Max. 10–20
Fine Aggregate Angularity	ASTM C 1252	47.85	Min. 40

Aggregate gradation had been chosen in conformity with the Type-I wearing course of Turkish Specifications. The properties of the limestone aggregates were presented in Table 2.
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 [30–32]. In this research, the organic additive content was chosen as 3.0%. The utilization of this content is based on a past research made by [12]. They concluded that this organic additive should be added at a rate of 3.0% by weight of bitumen for maximum effectiveness.
Rediset® WMX is a chemical additive that uses a combination of cationic surfactants and organic additive based rheology modifier. this additive chemically modifies the bitumen and obtains active adhesion force which improves coating of aggregates with bitumen [17]. this chemical additive can also encourage both processing of asphalt mixture at lower temperatures. Researches indicate that the chemical additive should be used at dosage rates at 1.5%, 2% and 3% by weight of the bitumen for better performance of mixture [16–19]. In this research, the chemical additive content was chosen as 2.0% taking the recommendation of supplier company [19].
The RAP material to be utilized within the asphalt mixtures was obtained from seven years old wearing course section of an asphalt pavement where is located on one of the main arterials in Izmir city.

2.2. Test methods

2.2.1. Conventional bitumen tests

The base bitumen and the bitumen samples containing organic and chemical additives 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) [20–22]. 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 [33].
The viscosity defined as resistance of a fluid to flow is significant since it affects the workability of the bitumen [34]. Brookfield viscometer was employed to inspect the mixing and compaction temperatures of the mixtures in according to ASTM D4402-06 [35]. The test was performed at 135°C and 160°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.

2.2.2. Determining properties of RAP

In order to determine the bitumen content within the aged bituminous mixtures, ten batches (each of 1000 grams) of RAP were prepared and extraction of bitumen was performed from each of the batch with a laboratory type centrifuge extractor called Rota Test.
In order to characterize the properties of the old bitumen obtained from the extraction test, above mentioned conventional tests were performed. The properties of the old bitumen are presented within the Table 5. Besides, sieve analysis test were performed on the extracted aggregates. Results for sieve analysis of extracted aggregates are given in Table 6.

2.2.3. Marshall stability and flow analysis

The Marshall method has been applied on HMA and WMA samples involving different contents of RAP as well as on control samples in terms of stability, flow and air void content (ASTM D3549-11) so as to evaluate the effect of RAP [36].

2.2.4. 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 [37]. 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 [38]. 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. For each mixture assessed in this study, two specimens of same mixture 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 DISCUSSIONS

3.1. Conventional test results

The conventional properties of the bitumen prepared with organic and chemical additives are presented in Table 3.
As depicted in Table 3, the addition of the WMA additives decreased the penetration values and increases the softening point values.
As seen in Table 3, all WMA samples exhibit higher penetration index values (which is an indicator of reduced temperature susceptibility) compared to base bitumen. Besides among all the WMA additives, organic WMA additive exhibits the lowest temperature susceptibility. Asphalt mixtures containing bitumen with higher PI are more resistant to low temperature cracking as well as permanent deformation [39].
Storage stability test indicate that, the bitumen samples prepared with chemical additive are much more storage stable compared to other WMA samples containing organic additive.
As depicted in Table 3, the additives reduce the viscosity of bitumen which indicates that, all WMA additives increase the workability and make relatively reductions for mixing and compaction temperatures. The viscosity of results related to each WMA additive 135°C and 160°C are drawn at semi logarithmic figure and the temperature corresponds to compaction and mixing range is also summarized in Table 4.
The addition of organic and chemical WMA additives reduced the mixing temperature by 13°C and 9°C respectively. Besides, the addition of mentioned additives reduces the compaction temperatures by 10°C and 8°C respectively.

Table 3: Conventional properties of bitumen prepared with warm mix asphalt additives.

WMA Additive Types	Contents (%)	Pen. (0.1mm)	Softening Point(°C)	Viscosity (mPa.s) 135°C	Viscosity (mPa.s) 160°C	Thin Film Oven Test (TFOT) Loss of mass(%)	TFOT Retained Pen.(%)	TFOT Soft.Point diff.(°C)	Rolling Thin Film Oven Test (RTFOT) Loss of mass(%)	RTFOT Retained Pen.(%)	RTFOT Soft.Point diff. (°C)	RTFOT Pen. Index (PI)	Storage Stability (°C)
Organic	**0**	55	49.1	412.5	137.5	0.04	75	5.0	-0.04	74	5.3	-1.20	
	3	37	69.3	287.5	75.0	0.07	87	4.0	-0.07	85	4.3	1.95	1.6
Chemical	**0**	55	49.1	412.5	137.5	0.04	75	5.0	-0.04	74	5.3	-1.20	
	2	44	56.7	337.5	87.5	0.04	84	2.5	-0.07	83	2.5	0.04	0.5

Table 4: Mixing and compaction temperatures.

Additives	Contents (%)	Mixing Temp.(°C)	Compaction Temp. (°C)
Base Bitumen	0	156-163	143-149
Organic	3	144-149	134-138
Chemical	2	148-153	133-142

3.2. Determining properties of RAP

Based on the extraction test results, the average bitumen content was determined as 4.30 % based on ten batches of RAP samples. Conventional bitumen tests result conducted on the old bitumen is presented in Table 5.

Table 5: Properties of the old bitumen.

Test	Specification	Results
Penetration (25 °C; 0.1 mm)	ASTM D5 EN 1426	23
Softening Point (°C)	ASTM D36 EN 1427	72.9
Penetration Index (PI)		1.45
Viscosity at (135 °C)-Pa.s	ASTM D4402	0.563
Viscosity at (165 °C)-Pa.s	ASTM D4402	0.138
Thin Film Oven Test (TFOT) (163°C; 5 hr)	ASTM D1754 EN 12607-1	-
Change of Mass (%)		0.02
Retained Penetration (%)	ASTM D5 EN 1426	82
Softening Point Diff.after TFOT (°C)	ASTM D36 EN 1427	1.9

As RAP bitumen reacts and loses some of its components during the construction process (short term aging) and service life of the road (long term aging), its rheological behavior will naturally differ from virgin materials. During aging process, bitumen is exposed to hot air at high temperatures ranging from 135°C to 160°C, resulting in a significant increase in viscosity. Besides, bitumen loses many of its oil components during construction and service resulting in a high proportion of asphaltenes in the blend, which leads to increased stiffness and viscosity.
Sieve analysis was performed on the extracted aggregates which are presented in Table 6. The mix gradation (10%, 20%, 30%, 40% and 50% of the RAP and 90%, 80%, 70%, 60% and 50% of new aggregate) must meet the requirements of Turkish Specifications related to the Type I Wearing Course construction.

Table 6: Sieve analysis results for extracted aggregates.

Sieve No	Cumulative Weight Passing (gr)	% Retained	% Pass
3/4"	13299	0	100
1/2"	13092	1.6	98.4
3/8"	11966	10.1	89.9
No.4	7197.5	45.9	54.1
No.10	4016	69.8	30.2
No.40	1792.5	86.5	13.5
No.80	1173	91.18	8.82
No.200	775	94.17	5.83

3.3. Marshall stability and flow analysis

The optimum bitumen content related to HMA and WMA including organic and chemical additives were determined (by the Marshall analysis) as 4.88%, 4.30% and 4.53%, respectively.
After determining the contents of the new bitumen to be added into mixture with respect to the values are given in Table 7. HMA samples and the asphalt concrete samples including two different kinds of WMA additives with different percentages of RAP were prepared taken into the mixing and compaction temperatures into consideration. Within the scope of this study, Marshall stability and flow methodology is referenced to determine RAP contents. Although comparative study of different additives and bitumen can be possible through a unique test method, it should be considered that different methodologies such as Hveem and/or Superpave mix design methods would result in higher applications of RAP contents.

Table 7: Calculation of the percentage of the bitumen to be added in the mix based on RAP content for each of the additive.

TYPES OF MIXTURE	RAP Content (%)	Pc (%) Total bitumen in the mix	Pa (%) Bitumen content of RAP	Pr (%) Bitumen content to be added into the mix
HMA	10	4.88	4.3	4.45
	20			4.02
	30			3.59
	40			3.16
	50			2.73
WMA + Organic Additive	10	4.3		3.87
	20			3.44
	30			3.01
	40			2.58
	50			2.15
WMA + Chemical Additive	10	4.53		4.10
	20			3.67
	30			3.24
	40			2.81
	50			2.38

The mechanical properties of different RAP percentages with HMA and all warm mix additives in terms of stability, flow and voids are presented in Figure 1, Figure 2 and Figure 3 respectively.

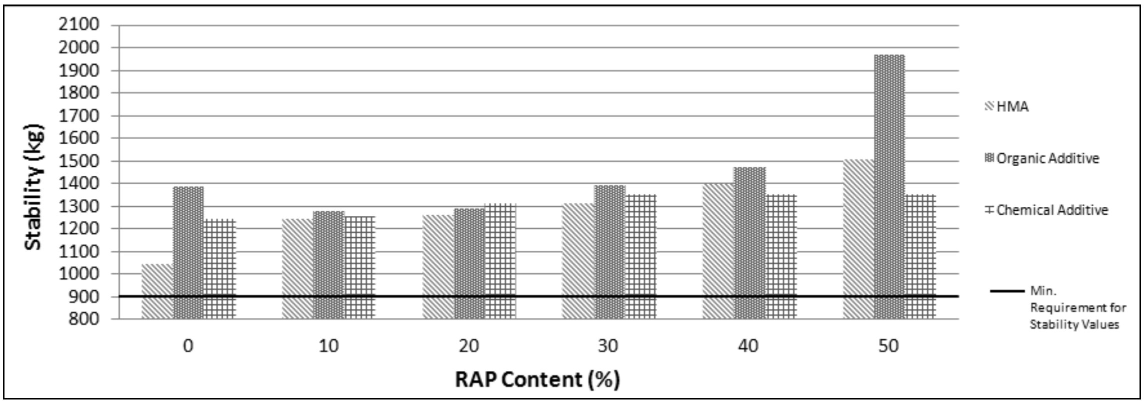

Figure 1: Marshall stability values for RAP and control samples.

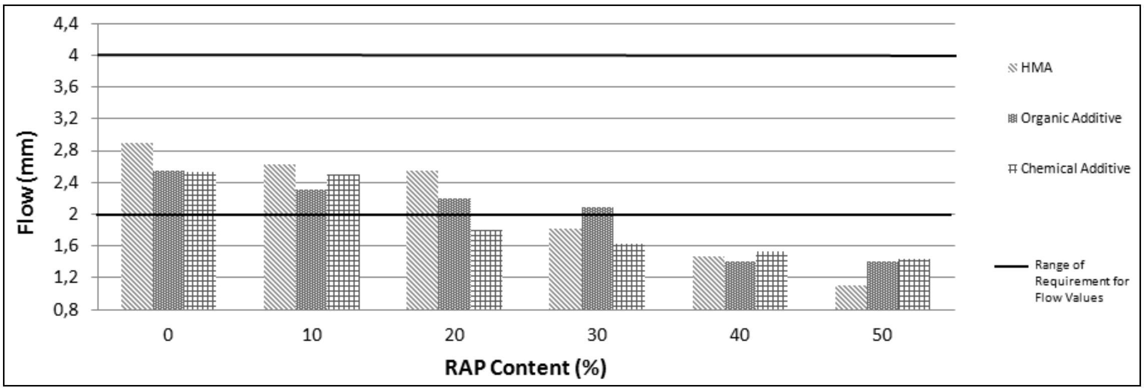

Figure 2: Flow values for RAP and control samples

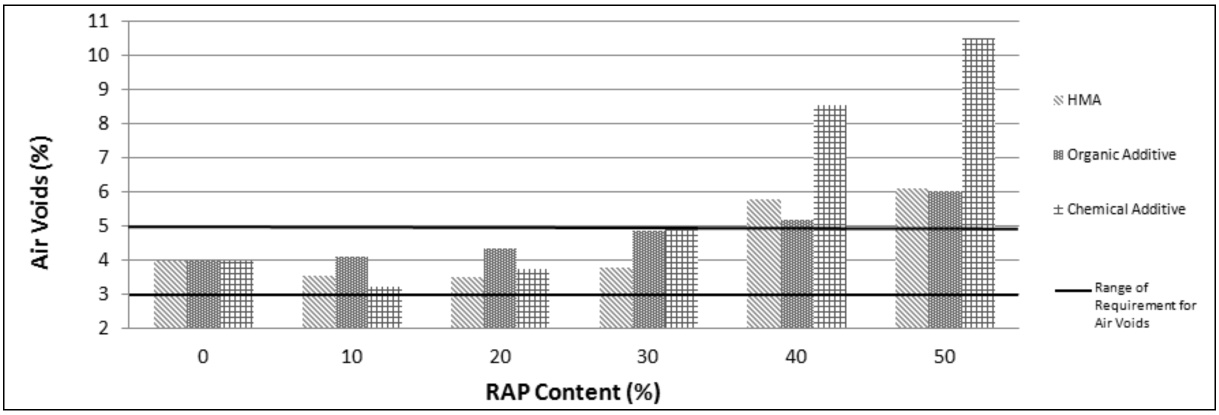

Figure 3: Air void values for RAP and control samples

As illustrated in Figure 1, all recycled asphalt mixtures involving HMA and all WMA additives provide adequate stability (min. 900 kg. related to wearing course specification). The stability values increases with the increase of RAP content for HMA and the mixtures prepared with organic. However, no significant variation is observed on the stability values above 30% RAP content addition for the mixtures involving chemical additive.

As presented in Figure 2, the flow values decrease with increasing RAP content for HMA mixtures and the mixtures prepared with all WMA additives. As the flow values are indicator of deformation characteristic, the flow values less than the specification limits (2 mm.) is not favorable since it implies that the mix is very stiff and brittle. As depicted in Figure 2, more than 20%, 30% and 10% addition are below the specification limits of flow values for HMA and mixtures prepared with organic and chemical respectively.

Therefore, it can be concluded that the 20% RAP content with HMA, 30% RAP content with organic additive, 10% RAP content with chemical additive can be accepted as an optimum RAP content based on the specification limits of flow and stability values.

As illustrated in Figure 3, as RAP contents increase, the voids increase as well for HMA and all specimens involving WMA additives. Besides, the concluded optimum RAP contents for HMA and each WMA additive satisfies the specification limits of air voids value (3%-5%).

3.4. Rutting Test Results

The Hamburg wheel tracking test was performed in accordance with EN 12697-22 standard [38]. The rut depths at 50°C are presented in Figure 4. 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 optimum RAP contents were determined at each 5.000 passes initiating at 5.000 and ending at 30.000.

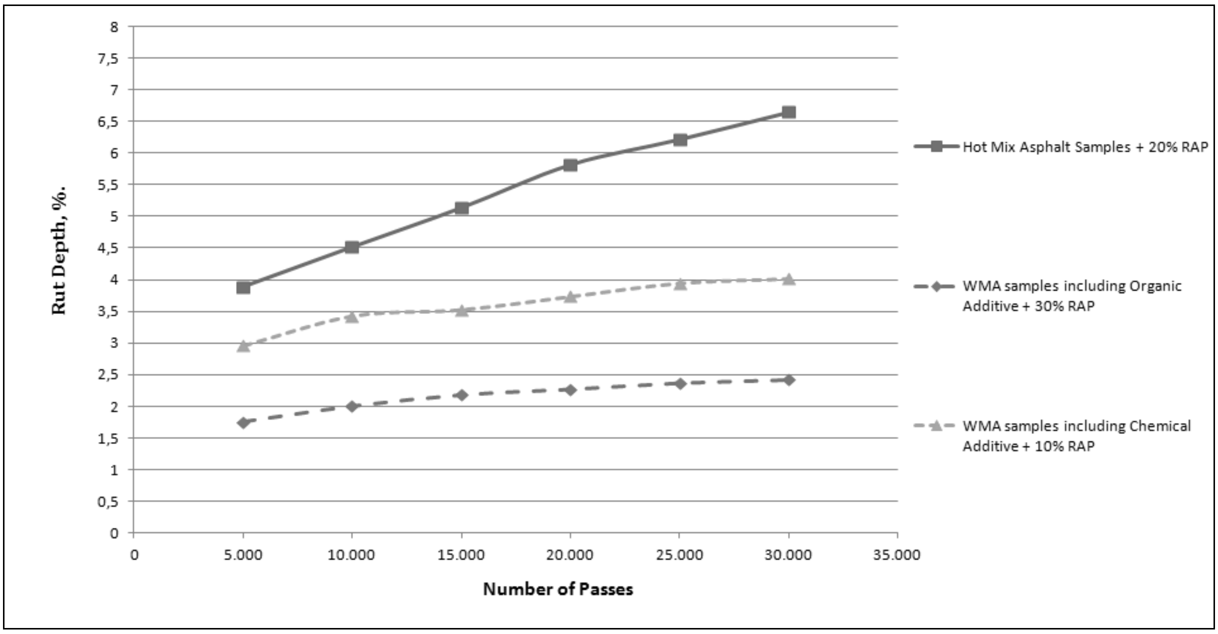

Figure 4: The rut depth percent values corresponding number of passes for mixtures including optimum RAP content

As expected the rut depth values typically increased with increase in the number of passes. Based on each number of passes, all WMA mixtures involving optimum RAP contents performed better than HMA mixture in terms of rut depth. The resistance of mixtures against rutting susceptibility is significantly improved by the utilization of organic WMA additive together with 30% RAP content.

4. CONCLUSIONS AND RECOMMENDATIONS

Lowering asphalt production emissions in the plant and compaction emissions in the field are the most important benefits of utilization of WMA. The properties of bitumen are improved by means of organic and chemical WMA additives. These results have been reached by the conventional test methods such as penetration, softening point, rotational viscosity, TFOT test results. Besides, the utilization of organic and chemical additives help in the reduction of viscosity values which are in return decreases mixing and compaction temperature leading to the reduction of energy costs as well as emissions. Since the production of WMA additives demands energy and would result in extra emissions itself, a comprehensive study should be conducted in order to correctly define WMA additives roles in overall contribution of these additives in global issues such as energy and emissions.

Based on the utilized aggregate, 20%, 30% and 10% can be accepted as an optimum RAP contents related to HMA samples, organic and chemical additives respectively. The other properties of samples including optimum RAP content for HMA mixtures and each WMA additive are also within specification limits in terms of flow, air void level.

In the light of findings from rutting test, it is possible to consider that the WMA additives used within the scope of this study improve resistance to rutting characteristics of bituminous mixtures. Organic and chemical additives have structural modification effects on bituminous mixtures. For a specified number of passes (15.000 passes e.g.) the mixtures involving organic additive exhibit the lowest rut depth percentage. This result is attributable to crystallized structure arising from the modification effect of organic WMA additive.

Overall, WMA mixtures prepared with optimum RAP content used in this study perform better than HMA mixtures containing 20% RAP in terms of rutting characteristics. Beside modification effects of WMA additives, the lower amount of aging due to lower application temperatures play an important role in total assessment of these innovative technologies.

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